Optimising Electrical Wiring Design of a Single-Storey Floor Plan using Multi-Objective Ant Colony System Algorithm (MOACS-EWR)

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Abstract

Nature-inspired algorithms are remarkable of producing optimum solutions by using the extraordinary behavior of nature. Ant colony optimisation algorithm is a foremost algorithm applied to various difficult combinatorial optimisation problems and proved successes. This research introduces a novel approach to optimise the electrical wire routes in the single-storey building through 2D walls. This study explores the applicability of Multi-Objective Ant Colony Algorithms for Electrical Wire Routing (MOACS-EWR) when optimizing the wire routes through the walls of a single-storey building. MOACS-EWR algorithm can optimise multiple objectives, length of the path and the number of bends in the path. The study was conducted using several models of rooms and finally the single-storey floor plan. Results show that MOACS-EWR algorithm can find the optimised wire routes in a floor plan.

Keywords: nature-inspired algorithms, *ant colony optimisation algorithm*, *electrical wire routing*, *multi-objective optimisation*, *MOACS-EWR*

1. Introduction

Solutions from nature are one of the best ways to address the current world issues. Real world optimisation problems are difficult to solve, and one of the efficient ways to solve these problems is to use nature-inspired algorithms. Some nature-inspired algorithms such as genetic algorithms, particle swarm optimisation, cuckoo search algorithm, firefly algorithm, and ant colony optimisation (ACO) algorithms are prevalent due to their highly dynamic nature (Jr Fister et al., 2013). Out of these algorithms, the ACO algorithm that mimics the behavior of ants is exceptional, and scientists have studied the behavioral patterns of ants to solve many real-world problems (Bonabeau et al., 1999).

Ant colony algorithm is a kind of collective algorithm, inspired by the foraging behavior of ants. Ants are amazingly capable of finding the shortest path between their nest and the source of food. Actual communication is done by following the pheromone trails laid by ants, and the ants follow the footprints depending on the intensity of the pheromone trail on the path (Alaya et al., 2007). If a path has a stronger pheromone trail, there is a high possibility of other ants following this path (Dorigo and Stützle, 2004). This phenomenon automatically leads the ants to follow the shortest path.

In this paper, Multi-Objective Ant Colony Algorithms for Electrical Wire Routing (MOACS-EWR) are introduced to optimise electrical wire routes considering multiple objectives, length of the route and the number of bends in the route. Initially MOACS-EWR is developed considering single walls (Pemarathne and Fernando, 2020). In this research we have applied the algorithm to an entire room environment with

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four walls. In order to test the behavior of the algorithm the rooms are designed as 2D grids considering all the possible directions to reach to the end point.

Electrical cabling is a critical factor that needs to be addressed carefully in building constructions. Best optimised layouts of circuits improve the manageability by reducing the difficulties and the cost of the entire wiring system (Pemarathne and Fernando, 2016). Through the past decades, electrical requirements grew rapidly, making wiring designs more complicated for manual performance. Electrical wiring design must follow the recognised standards like IET (The Institution of Engineering and Technology), which is also known as BS7671, defined as the standard regulations for wiring (Locke, 2008). These regulations are essential to electrical engineers and installation designers for proper and secure electrical installations (Stokes and Bradley, 2009). In this study, the standard mounting heights of electrical accessories were considered when designing the models of the grids (walls).

The algorithm is applied through two approaches: In the first approach, optimised path is selected considering the all possible routes between the start and the target points. In the second approach we allow the ants to follow only the vertical and horizontal paths to reach to the target. Finally, the approach of applying the algorithm to find optimised wire routes in the single floor plan connecting all the rooms are explained.

2. Materials and Methods
2.1 Multi Objective Ant Colony System Algorithm for Electrical Wire Routing (MOACS-EWR)
MOACS-EWR algorithm is derived from Ant Colony System (ACS) with several modifications to achieve optimised wire routes. First modification is done to the ACS state transition rule in equation 1. Normally, an ant k in point r selects the next point s based on either exploitation or exploration. This is selected using a random number q which is uniformly distributed in [0, 1], and q_0 is a parameter ($0 \leq q_0 \leq 1$) in the algorithm. In this experiment q_0 is taken as 0.9, and if $q \leq q_0$, normal ACS exploitation rule is applied. Otherwise ants use biased exploration to select the next point. In this situation, the random proportion rule in equation 2 is used to calculate the probability of selecting the next point. In ACS, the heuristic information in the random proportion rule is taken by considering 1/distance (r, s) from the point r to the point s. However, in this study the heuristic information is modified to select 1/distance (s, t) from the next possible point (s) to the target point (t) to make the solution more feasible.

After calculating the probabilities of moving to the next possible cities, roulette wheel selection is applied to select the next city, by generating a random number between [0, 1] and comparing it with the calculated probabilities. This encourages ants to explore more paths depending on their probabilities. The paths with high values of probability get higher chance to be selected.

In this algorithm, ants design the circuit by travelling from the starting point to the ending point where the socket outlet is located. Initially, all ants in the colony placed in the starting point. Then each ant selects the next grid point to move according to the modified state transition rule explained as in equations 1 and 2 with roulette wheel selection. This selection is made according to the closest (to the ending point) and the highest level of pheromone. Then the ants apply the local pheromone updating rule in equation 6 to update the pheromones in the visited edges of their constructing tour. When ants reach to the target point where the power socket is located, tour is completed. After all ants complete their tours, the total lengths of their tours are calculated. Then the best path is selected and the pheromones of the edges of that path are updated with extra amount of pheromones according to the modified global updating rule in equation 3.

Global updating rule in equation 3 is the next modification to achieve the optimised path with minimum length, minimum number of bends and straight angles. This study uses weighted sum approach when designing the objective function to optimise multiple objectives. The pheromones are updated in the iteration best path according to the designed objective function which optimises the length, the number of bends and the angles of the bends. Modifications are further explained in the next section. Heuristic functions are designed with considering the normalization of both continuous and discrete quantities.

A. An ant position on city r chooses the city s to move, by applying the state transition rule (pseudo-random-proportional rule) is given by equation 1.

$$s = \begin{cases} \arg\max_{u \in J_k(r)} \left[[\tau(r,s)] \cdot [\eta(r,s)]^\beta \right] & \text{if } q \leq q_0 \text{ (exploitation)} \\ S & \text{otherwise (biased exploration)} \end{cases} \tag{1}$$

where: $\tau(r,s)$ is the pheromone density of an edge (r,s), heuristic information $\eta(r,s)$ is the [1/distance $((s,t))$], reciprocal of distance from point s to the target point t. $J_k(r)$ is the set of cities that remains to be visited by ant k positioned on city r. $\eta(r,u)$ is also taken as [1/distance $((s,t))$] β is a parameter which decides the relative importance of pheromone versus heuristic ($\beta>0$). q is a random number uniformly distributed in [0,1], q_0 is a parameter ($0 \leq q_0 \leq 1$), and S is a random variable from the probability distribution given by the equation 2.

$$p_k(r,s) = \begin{cases} \dfrac{[\tau(r,s)] \cdot [\eta(r,s)]^\beta}{\sum_{u \in J_k(r)} [\tau(r,u)] \cdot [\eta(r,u)]^\beta} & \text{if } s \in J_k(r) \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

B. Then the pheromones are updated in the edges of the best ant tour using the global updating rule given in equation 3.

$$\tau(r,s) \leftarrow (1-\alpha) \cdot \tau(r,s) + \alpha \cdot \Delta\tau(r,s) \tag{3}$$

where: $0<\alpha<1$ is the pheromone decay parameter.

Objective function is modified to minimize the total length of the circuit (L_{gb}) and the number of bends (N_B) in a circuit.

$$\Delta\tau(r,s) = \begin{cases} (f)^{-1} & \text{if } (r,s) \in \text{global-best-tour} \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

$$f = w_1 \left(\frac{L_{gb}}{2D}\right) + w_2 \left(\frac{N_B}{4}\right) \tag{5}$$

where:
$w_1+w_2=1$
L_{gb} length of the global best tour
D is the diagonal length of the plot
N_B is the number of bends in the global best tour
4 is the maximum no of bends allowed before a circuit breaker is met.

w_1 and w_2 are the weighting factors associated with the length and the number of bends respectively. They should be selected according to the proportion of importance being given to one objective over the other. The sum of the weights is equal to one. This method was used to select the

optimised path considering multiple objectives. w_1=0.6, w_2=0.4 is the best weight combination found after several experiments have been carried out (Pemarathne and Fernando, 2020).

C. When ants move from one city to another city, local pheromone updating rule is applied as in equation 6.

$$\tau(r,s) \leftarrow (1-\rho) \cdot \tau(r,s) + \rho \cdot \Delta\tau(r,s) \tag{6}$$

where: $0 < \rho < 1$ is a parameter and $\Delta\tau(r,s) = \tau_0$, τ_0 is the initial pheromone level.

D. Roulette Wheel Selection

Using the roulette wheel selection, the probabilities calculated by the state transition rule in equation 2 to select the next city to move, are mapped into contiguous segments of a line span within [0, 1] such that each individual's segment is equally sized to its probability. A random number is generated and the individual whose segment spans the random number is selected.
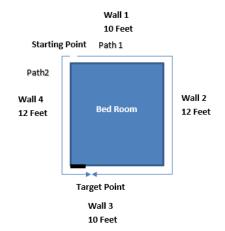
2.2 Methodology
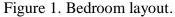*a) Application of MOACS-EWR to optimise the electrical wire designs of a single room*

Experimentation was carryout by applying MOACO-EWR to provide the best possible optimised paths for electrical wire routes in an entire room environment. In this experimentation we have considered only wiring through the walls. The algorithm is applied through two approaches. The first approach explained in section 2.2.3, we develop the algorithm to find the optimise path considering all the possible paths between the starting and target points. In the second approach in section 2.2.4 algorithm is applied considering only the horizontal and vertical paths to reach to the target point. We have considered four models of different types of rooms for the experimentation; bedroom (Model 1), bathroom (Model 2), kitchen (Model 3) and living room (Model 4). All four models were represented in the grid format as explained in the next section 2.2.1. Finally, the approach of applying the algorithm to find optimised wire routes in the single floor plan connecting all the rooms is explained in section 2.2.5.

b) Designing the grid of room layout to achieve the optimised path
Model 1: Bedroom

All four walls in the room represented in a single grid. Walls 1 and 3 are 3.05 m long, and walls 2 and 4 are 3.58 m. Wall 3 consists of one obstacle, a door. The starting point of the wire route is on the left side of wall 3, while the final target is in wall 3 close to the door. There are two possible directions to reach the target point in two directions, path 1 and path 2 (Figure 1). We modified the algorithm to find the optimised path to reach the target considering both directions.

According to Figure 2, the grid is designed as a 2D-layout representing all four walls. An index line is created as the joint of walls 1 and 4, where the starting point is located. The positive side of the grid represents wall 1, wall 2, wall 3, and wall 4, while the negative side represents the adjoining wall 4 and wall 3 of the other side of the wall 1 with the starting point. This representation was applied because there are two different directions, as shown in Figure 1 paths 1 and 2, to reach the target from the starting point. Since there are two directions to the target, the target point is represented as two targets in the grid, but both are in the same point in the same wall. Target 1 is at point 7 (-16, 0.5) and left to the starting point 157 (0, 9), and target 2 is at point 51 (28, 0.5) right to the starting point. The grid consists of 201 points 0.3 m apart and represented in Figure 2.
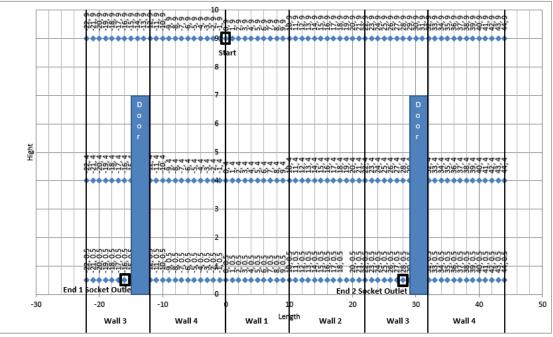
Figure 1. Bedroom layout.

Figure 2. Grid of the bedroom.

Model 2: Bathroom

All four walls in the bathroom are represented in a single grid in Figure 3, walls 1 and 3 are 1.83 m long, and walls 2 and 4 are 2.44 m. Wall 1 has one obstacle, a door, whereas wall 3 consists of another obstacle (window). The starting point is in the joint corner of wall 1 and wall 2. The final target is on wall 4. There are two possible directions to reach the target point in two directions. We have modified the algorithm to find the optimised path to reach the target, considering both directions.

As shown in Figure 3, the grid is designed as a 2D-layout of all four walls. An index line is created at the joint of walls 1 and 4. The positive side of the grid represents wall 1, wall 2, wall 3, and wall 4, and the negative side represents the adjoining wall 4 of the other side of wall 1. This design was applied because there are two different directions to reach the target from the starting point. Since there are two directions to the target, the target point is represented as two targets in the grid, but both are in the same

point in the same wall. Target 1 is at point 35 (-7, 4) and left to the starting point 81 (6, 9), while target 2 is at point 59 (21, 4) right to the starting point. The grid consists of one foot apart 100 points.
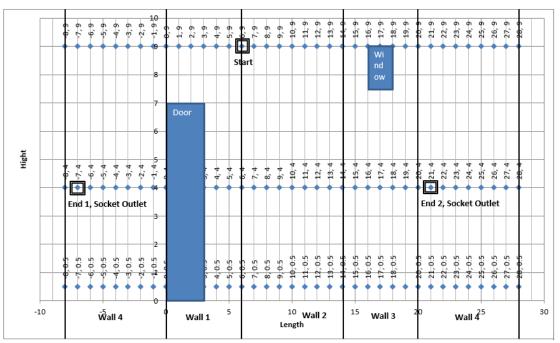

Figure 3. Grid of the bathroom.

Model 3: Kitchen

All four walls in the room are represented in a single grid, and walls 1, 2, 3, and 4 are 3.66 m in length. Wall 1 has one obstacle, door 1. Wall 3 has two obstacles, door 2 and a window. The starting point is in the joining corner of walls 1 and 2, and the target is in wall 4. There are two possible directions to reach the target point in two directions. We modified the algorithm to find the optimised path to reach the target, considering both directions.
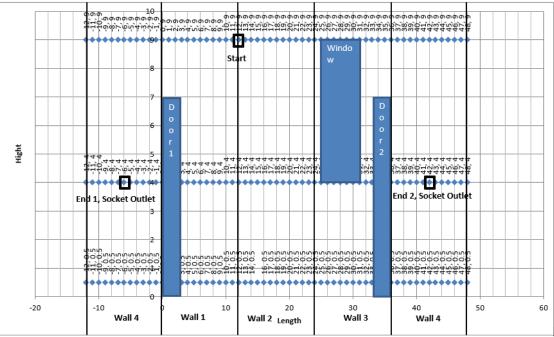

Figure 4. Grid of the kitchen.

According to Figure 4, the grid is designed as a 2D-layout of all four walls. An index line is created at the joint of walls 1 and 4. The positive side of the grid represents wall 1, wall 2, wall 3, and wall 4, while the negative side represents the adjoining wall 4. This representation was applied because there are two different directions, as shown in Figure 4 path 1 and 2, to reach the target from the starting point. Since there are two directions to the target, the target point is represented as two targets in the grid, but both are in the same point in the same wall. Target 1 is at point 60 (-6, 4) and left to the starting point 124 (12, 9), and target 2 is at point 93 (42, 4) right to the starting point. The grid has 153 points 0.3 m apart.

Model 4: Living room

All four walls in the room are represented in a single grid as Figure 5. Walls 1 and 3 are 6.10 m in length, and walls 2, and 4 are 4.88 m. Wall 3 consists of one obstacle, a window, and wall 4 has another obstacle, a door. The starting point is in wall 1, and the final target is in wall 4, close to the door. There are two possible directions to reach the target point in two directions. We have modified the algorithm to find the optimised path to reach the target considering both directions.

As shown in Figure 5, the grid is designed as a 2D-layout of all four walls. An index line is created at the joint of wall 1 and 4, where the starting point is located. The positive side of the grid represents wall 1, wall 2, wall 3, and wall 4, while the negative side represents the adjoining wall 4 and wall 3 of the other side of the wall 1 with the starting point. This representation was applied because of the two different directions, as shown in Figure 5 paths 1 and 2, to reach the target from the starting point. Since there are two directions to the target, the target point is represented as two targets in the grid, but both are in the same point in the same wall. Target 1 is at point 8 (-12, 0.5) and left to the starting point 154 (4, 9), while target 2 is at point 58 (60, 0.5) right to the starting point. The grid has 205 points one foot apart.
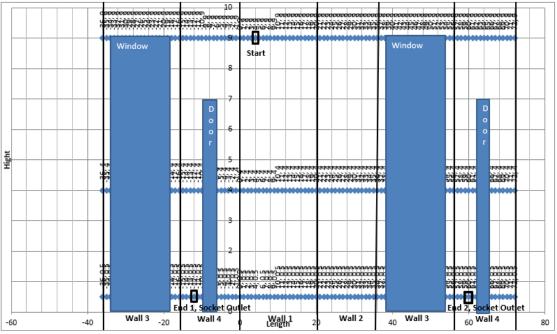

Figure 5. Grid of the living room.

c) Approach 1: The optimised path is selected considering all possible paths

In this approach, all ants were placed in the starting point, and then applied the MOACO-EWR algorithm. All ants were given two target points; when an ant reaches a target point, its journey is over. While they construct the tour, the next point is selected according to the state transition rule in equation 1.

The local pheromone updating rule in equation 6 is applied to the visited edge. After all ants finalized their tours, the global pheromone updating rule in equation 3 with the modified heuristic function of equation 4 and 5 is applied to the shortest path, followed with the extra pheromone updating. This has been applied through 1,000 iterations, and the global best path is calculated. This process was repeated for 10 trials in a single run to make the solution more accurate.

Multi-objective optimisation of length and number of bends were tested. The no. of ants=20, no. of turns the algorithm is run is MAX_TURN=1,000, pheromone decay parameters are ρ=0.1, α=0.1, β=2, q_0=0.9, w_1=0.6, w_2=0.4, and τ_0=$(n.L_{nn})^{-1}$ where L_{nn} is the tour length produced by the nearest neighbor heuristic and n is the number of cities. The heuristic distance $\eta(s,t)$, the [1/distance $((s,t))$] is the distance from point s to the target point (socket outlet). This will make the solution more effective and feasible. The diagonal distance of the grid (D) changes according to the room; Bedroom: D=70, Bathroom: D=37, Kitchen: D=61, and the Living room: D=108.

The simulations were conducted on a PC with Intel Core i5-6200U processor (Processor speed=2.4 GHz, Memory=8 GB) in Windows 10 Home-operating system using MATLAB (Version R2012b). The experimentation was carried out using four models of different types of rooms; bedroom (Model 1), bathroom (Model 2), kitchen (Model 3), and living room (Model 4).

d) Approach 2: Considering only the horizontal and vertical paths only
In this approach, the ants were directed to take only vertical and horizontal paths when moving towards the target. Initially, the modified state transition rule in equation 1 and roulette wheel selection are applied to select the next city to move. In this approach, after the next point is selected according to the above method, the angle between the current point and the selected next point is compared against the angles of 0º, 90º, 180º, and 270º. If the angle between the points does not match with the above angles, ants must select another point using the same method, and this will repeat until meeting with the angle criteria. Ants must repeat this process and build the tour towards the target point by only following horizontal and vertical paths.

Initially, all ants were placed in the starting point, followed by the application of the MOACO-EWR algorithm. All ants were given two target points, and when an ant reaches a target point, its journey is completed. While they construct the tour, the next point is selected according to the state transition rule in equation 1. The local pheromone updating rule in equation 6 is applied to the visited edge. After all, ants finalized their tours, the global pheromone updating rule in equation 3 with modified heuristic function in equation 4 and 5, and one is applied to the shortest path, followed by extra pheromone updating. This was applied through 1,000 iterations and calculated the globally best path. This process was repeated for 10 trials in a single run to make the solution more accurate.

A single-objective optimisation for length and multi-objective optimisation of length and number of bends were tested. The no. of ants=20, no. of turns the algorithm is run is MAX_TURN=1,000, pheromone decay parameters are ρ=0.1, α=0.1, β=2, q_0=0.9, w_1=0.6, w_2=0.4, and τ_0=$(n.L_{nn})^{-1}$ where L_{nn} is the tour length produced by the nearest neighbor heuristic, and n is the number of cities. The heuristic distance $\eta(s,t)$, the [1/distance $((s,t))$] is the distance from point s to the target point (socket outlet). This will make the solution more effective and feasible. The diagonal distance of the grid (D) changes according to the room: Bedroom: D=70, Bathroom: D=37, Kitchen: D=61, Living room: D=108.

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e) Application of MOACS: EWR for a single-storey floor plan

Finally, the floor plan in Figure 6 is designed with the individual room models we used for the experimentation in section 2.2.3 and section 2.2.4. The entire floor plan is consisting with the living room, kitchen, bathroom and the bedroom.
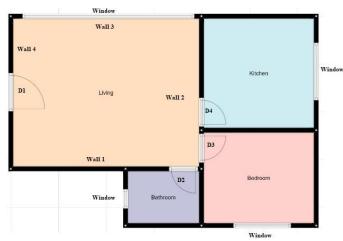

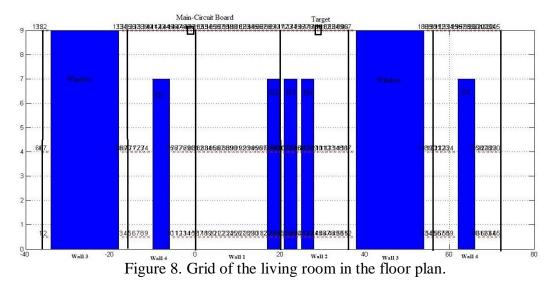Figure 6. Floor plan of a single-storey house.

According to Figure 7, we can see that the main circuit board in the living room distributes the wiring circuits to all the rooms in the floor. MOACS-EWR algorithm can apply to find the best possible paths to carry the electricity routes to the individual room where the electrical accessories are located. Installation Engineers and designers can prefer the most suitable approach from approach 1 and 2 stated in section 2.2.3 and 2.2.4. Approach 1 can be used with modified heuristic function explain in equation 4 and 5 when considering the all possible paths to reach to the target point. Approach 2 can be used with situations where the horizontal and the vertical wiring layouts are allowed.

Figure 7. Electrical distribution plan of a single-storey house four distribution circuit.

According to Figure 8, we have represented the grid of the living room in the floor plan. The grid was designed as a 2D-layout representing all four walls 1, 2, 3 and 4. An index line is created at the joint of wall 1 and 4, where the main circuit board is located. The positive side of the grid represents wall 1, wall 2, wall 3, and wall 4, while the negative side represents the adjoining wall 4 and wall 3. The wall 1 is consists with the starting point 150 (0, 9) where the main circuit board located. We have considered of

optimizing the path from main circuit board to the kitchen. So, that the target point 180 (30, 9) was presents at the wall 2. The grid is consisting with 205 points each one foot apart. We have applied the MOACS-EWR algorithm to optimise the path between the main circuit board and the target.

Figure 8. Grid of the living room in the floor plan.

3. Results and Discussion
3.1 Approach 1

Four models of rooms were tested in this experimentation. Model 1: Bedroom, Model 2: Bathroom, Model 3: Kitchen, and Model 4: Living room. For each model, the algorithm was repeated for ten trials in a single run to obtain an accurate solution. Results were recorded for ten runs and the best results were shown in the Table 1.

Model 1: Bedroom best path

According to Figure 9, the new algorithm can find the optimised path and reach the target. In this room, the target is represented as two destination points since one point is represented as the mirror image, but the target is positioned in the same wall in the same position. The direct distance between the start point 157 (0, 9) to the target two at point 51 (28, 0.5) is 8.92 m. The algorithm had chosen the shortest path to reach the target from the opposite direction 157 (0, 9), 141 (-16, 9), 7 (-16, 0.5), and the given best distance is 7.47 m with a single bend.
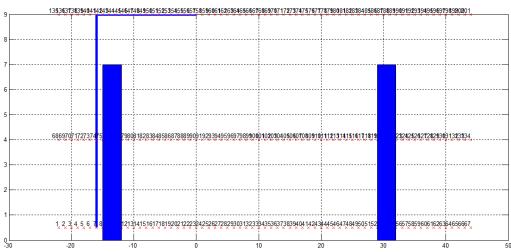

Figure 9. The best path of the bedroom (model 1) 157 (0, 9), 141 (-16, 9), 7 (-16, 0.5)-distance 7.47 m, number of bends 1.

Model 2: Bathroom best path

As shown in Figure 10, the algorithm produced the optimised path from the starting point to target one at point 35 (-7, 4) and left to the starting point 81 (6, 9). The path is 81 (6, 9), 79 (4, 9), 35 (-7, 4), distance 4.30 m, and with a single bend in the path. The direct distance between starting point 81 (6, 9) to target 2 is at point 59 (21, 4) is 4.82 m, which is the optimised distance between the start and target 2. When comparing the distances given by both directions, MOACS–EWR can find the shortest path to find the most appropriate direction when optimizing the wire route.
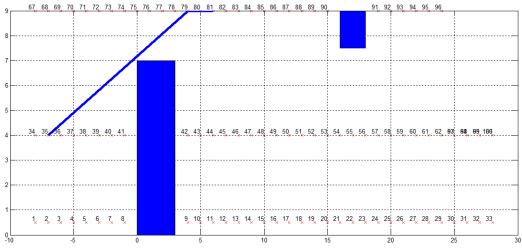

Figure 10. The best path of the bathroom (model 2) 81 (6, 9), 79 (4, 9), 35 (-7, 4)-
distance 4.30 m, number of bends 1.

Model 3: Kitchen best path

As in Figure 11, the optimised results given by the algorithm from the starting point 124 (12, 9) to the target 1 is at point 60 (-6, 4) in the left direction. The path is 124 (12, 9), 115 (3, 9), 60 (-6, 4), distance 5.88 m, and a single bend in the path. According to Figure 4, the distance from starting point 124 (12, 9) to the target 2 is at point 93 (42, 4), and the right side is longer than the distance given by the MOACS–EWR algorithm.
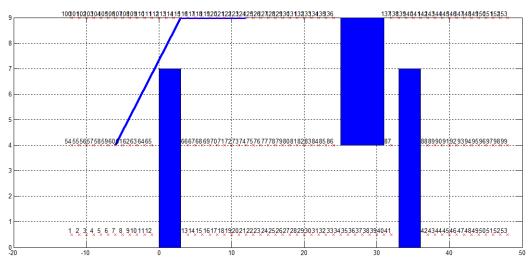

Figure 11. The best path of the kitchen (model 3) 124 (12, 9), 115 (3, 9), 60 (-6, 4)-
distance 5.88 m, number of bends 1.

Model 4: Living room best path

As per the result in Figure 12, the optimised path is from starting point 154 (4, 9) to target one at point 8 (-12, 0.5). The path is 154 (4, 9), 139 (-11, 9), 8 (-12, 0.5), distance 7.16 m, and a single bend in the path. According to Figure 5, the routing from starting point 154 (4, 9) to target two is at point 58 (60, 0.5) in the right side is not reachable because of the window (obstacle). MOACS–EWR algorithm can produce the best-optimised solution for the wire routing.
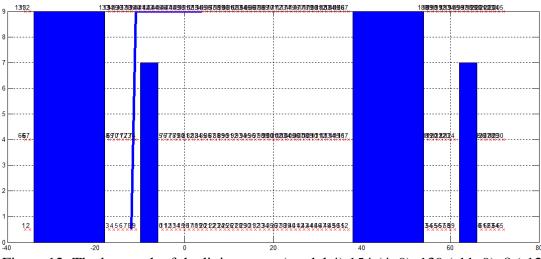

Figure 12. The best path of the living room (model 4) 154 (4, 9), 139 (-11, 9), 8 (-12, 0.5)-Distance 7.16 m, number of bends 1.

Table 1 provides a summary of the results for the room experiments in approach 1. Results contain the best paths given for each model of the room and the average statistics of 100 trials. The outcomes signify a slight deviation of the optimised distances of the models, bedroom, and bathroom. However, there is no difference in the best and the average results for the model's kitchen and living room. Results reveal that the MOACS–EWR algorithm produces the best-optimised solution for the wire routing when applying for a room environment.

Table 1: Summary of the results for rooms in approach 1.

Model	Best Path			Distance (m)	Bends	Time (seconds)	Average Distance (m)	Average Bends	Average Time (seconds)
Bedroom	157	141	7	7.47	1	21.9150	7.60	1	23.7792
Bathroom	81	79	35	4.29	1	20.6778	4.34	1	21.6560
Kitchen	124	115	60	5.88	1	41.1014	5.88	1	43.9299
Living room	154	139	8	7.16	1	100.1982	7.16	1	99.4642

3.2 Approach 2

In this experimentation, MOACS–EWR algorithm was applied to build the optimised vertical and horizontal wire routes only. We tested the same models for this approach; Model 1: Bedroom, Model 2: Bathroom, Model 3: Kitchen, and Model 4: Living room. For each model, the algorithm was repeated for ten trials in a single run to receive an accurate solution. Results were recorded for ten runs.

Model 1: Bedroom best path

As shown in Figure 13, the new algorithm can find the optimised path and reach the target while following the route through horizontal and vertical directions. Results were the same as the best results

given for approach 1. The algorithm had chosen the shortest path to reach the target from the opposite direction 157 (0, 9), 141 (-16, 9), 7 (-16, 0.5) and the given best distance is 7.47 m with a single bend.
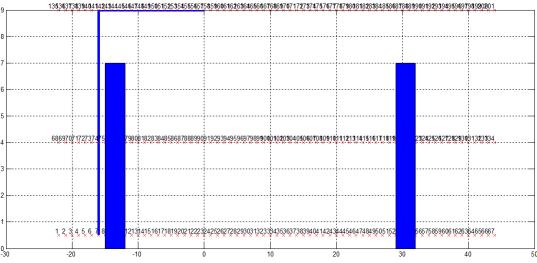

Figure 13. The best path of the bedroom (model 1) 157 (0, 9), 141 (-16, 9), 7 (-16, 0.5)- distance 7.47 m, number of bends 1.

Model 2: Bathroom best path

According to Figure 14, the algorithm produced the optimised path from the starting point to target one at point 35 (-7, 4) and left to the starting point 81 (6, 9). The path is 81 (6, 9), 68 (-7, 9), 35 (-7, 4), distance 5.49 m, and with a single bend in the path. The direct distance between starting point 81 (6, 9) to target 2 is at point 59 (21, 4) is 4.82 m. That is the optimised distance between the start and target 2. As shown in Figure 14, the new algorithm can find the optimised path and reach the target while following the route through horizontal and vertical directions. However, when the optimised results are compared, the first approach can find the most optimised distances, and that can apply to situations where the diagonal routes are allowed.
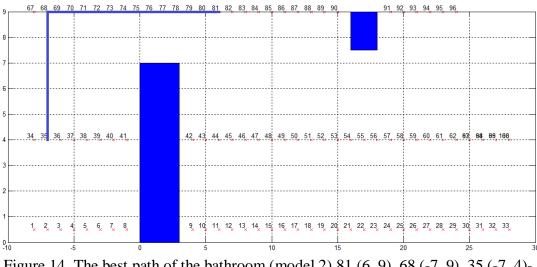

Figure 14. The best path of the bathroom (model 2) 81 (6, 9), 68 (-7, 9), 35 (-7, 4)- distance 5.49 m, number of bends 1.

Model 3: Kitchen best path

As per Figure 15, the new algorithm can find the optimised path and reach the target while following the route through horizontal and vertical directions. However, compared to the optimised results of both approaches, the first approach can find the most optimised distances, and that can apply to situations where the diagonal routes are allowed.
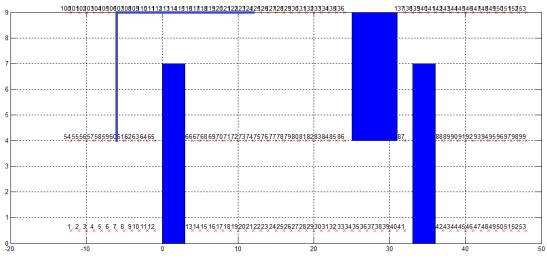

Figure 15. The best path of the kitchen (model 3) 124 (12, 9), 107 (-5, 9), 60 (-6, 4)- distance 6.71 m, number of bends 1.

Model 4: Living room best path

Results in Figure 16 indicate the optimised path is from the starting point 154 (4, 9) to target 1 at point 8 (-12, 0.5), the path is 154 (4, 9), 139 (-11, 9), 8 (-12, 0.5), distance 7.16 m, and a single bend in the path. According to Figure 5, the routing from starting point 154 (4, 9) to target two at point 58 (60, 0.5) in the right side is not reachable because of the window (obstacle). MOACS–EWR algorithm can produce the best-optimised solution for the wire routing. As in Figure 16, a new algorithm can find the optimised path and reach the target while following the route through horizontal and vertical directions.
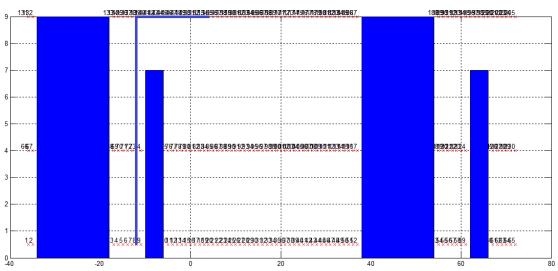

Figure 16. The best path of the living room (model 4) 154 (4, 9), 139 (-11, 9), 8 (-12, 0.5)- distance 7.16 m, number of bends 1.

3.3 Results of MOACS-EWR for a single-storey floor plan

Figure 17 illustrates displays the optimised path given by MOACS-EWR algorithm for wire route from main circuit board to the kitchen. Results of the section 3.1 and 3.2 prove that the MOACS-EWR algorithm is successful of providing optimise wire routes through the walls inside the rooms. Since, that the algorithm can apply to optimise the central wire routes from the main circuit board to the room, and then from that entering point to the targets inside the rooms.
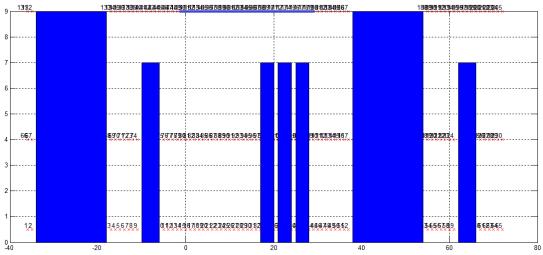

Figure 17. Optimised path given by MOACS- EWR algorithm from main circuit board to target at the living room on the floor plan.

4. Conclusion

Initially, the MOACO-EWR algorithm was developed to optimise wire routes in a single wall. In this study we have applied the algorithm to optimise wire routes in an entire room environment with four walls. We considered only wiring through the walls of a room in this aspect. The study was carried through two approaches. In the first approach, we developed the algorithm to find the optimised path considering all possible paths. The second approach was applied by considering the horizontal and vertical paths only. We have considered four models of different types of rooms for the experimentation; Bedroom (Model 1), Bathroom (Model 2), Kitchen (Model 3), and Living room (Model 4). In this study we have introduced a special designing strategy when designing the room grids. Finally, the approach of applying the algorithm to find optimised wire routes in the single floor plan connecting all the rooms are explained.

Results of the experimentations reveal that the MOACO-EWR is suited to optimise the wire routes in all room models, and it can define the most optimised paths. The algorithm was applied to identical four models of rooms with several similar obstacles, and (the algorithm) was capable of navigating through the most suitable direction to reach the target in the shortest path in less time. These proposed methods can help to optimise a wiring plan on a single- to the multi-story building environment.

Further MOACO-EWR algorithm produces the optimised paths with shortest length with less number of bends. Installation engineers and designers can select the most suitable approach from approaches 1 and 2 according to their requirements. Approach 1 can apply to routing through all possible points in the wall. Approach 2 can be used with the situations where the horizontal and vertical wiring layouts are allowed. Future algorithm can be embedded with an application where users can upload the floor plan with locations of points and obstacles; then the system will provide the optimised wiring layouts.

5. References

Alaya, I., Solnon, C. and Ghedira, K., 2007. Ant colony optimisation for multi-objective optimisation problems. In: *19th IEEE International Conference on Tools with Artificial Intelligence (ICTAI 2007)*, pp. 450-457.

Bonabeau, E., Dorigo, M. and Theraulaz, G., 1999. From natural to artificial swarm intelligence. Oxford University Press, Inc., New York, NY, USA.

Dorigo, M. and Stützle, T., 2004. Ant colony optimisation, A Bradford book. MIT Press, Cambridge, Mass.

Jr Fister, I., Yang, X.S., Fister, I., Brest, J. and Fister, D., 2013. A brief review of nature-inspired algorithms for optimisation, 7.

Locke, D., 2008. Guide to the Wiring Regulations 2008: IEE Wiring Regulations, 17 Rev Ed. Wiley-Blackwell, Hoboken, NJ.

Pemarathne, W.P.J. and Fernando, T.G.I., 2016. Wire and cable routings and harness designing systems with AI, a review. In: *2016 IEEE International Conference on Information and Automation for Sustainability (ICIAfS)*, IEEE, Galle, Sri Lanka, pp. 1-6.

Pemarathne, W.P.J. and Fernando, T.G.I., 2020. Ant colony optimisation algorithm to solve electrical cable routing. In: *Advances in Electronics Engineering*, Springer, Singapore.

Stokes, G. and Bradley, J., 2009. A practical guide to the wiring regulations: 17th Edition IEE Wiring Regulations, 4 Ed. Wiley, Chichester, U.K. Ames, Iowa.