Non-Overlapping Ratios as Fitness Function in Optimisation Spatial Layout Design

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***Abstract*—Arrangement of furniture inside a room can be one of many problems during concept generation stage. Finding an optimal arrangement of furniture or an optimal spatial layout design is vital to minimise a production cost. Also, an optimal spatial layout design will promote the movement of people inside the space reducing any possible injuries. Implementing optimisation algorithms will assist in finding feasible spatial layout design and generating thousands of solutions in shorter period. This paper studies the application of Genetic Algorithm in solving problems regarding spatial layout design. It basically finds the best placements for the furniture in a given space taking into consideration several constraints. Non-overlapping objects is one of the main constraints in spatial layout design requirements. Thus, using non-overlapping ratios as a fitness function could assist in evaluating the quality of the generated solutions.**

***Index Terms*—Spatial Layout Design; Genetic Algorithm; Optimisation; Fitness Function; Non-Overlapping.**

I. Introduction

Optimisation spatial layout design is to optimise the space needed for placement of things. It provides the optimum solution for the arrangement of given items and things within a space, a house for an example.

Spatial layout design is one of the most interesting but challenging stage of the formal architectural design problems. It has been studied by many researchers over a long period [1]. Spatial layout optimisation used for many purposes; mainly in designing, such as floor planning, building designing, and facility arrangement. This method will help a lot of people in the process of designing, planning spatial, architectural and geographical layouts

The aim of this paper is to study the effectiveness of genetic algorithms and methods of optimising spatial layout designs. To be specific, this paper focus more on genetic algorithms and studies the approaches to get the best results for optimising the spatial layout design, covering a wide range of spatial layouts from the smallest of projects like floor planning, to bigger scale projects like geographical layouts and city planning.

The general idea of the method presented in this paper called the "Optimisation Spatial Layout Design" provides solutions to layout problem. The brief idea of this method is to take the details of the furniture or items, the type (e.g.: tables, chairs, cupboards), the size, the shape. Then, allocates them into the available spaces and optimise the placements according the the design requirements. One of the design requirements in a real design exercises is that there will be no two objects in overlapped which each other's [2]. In this research, the non-overlapping requirements is interpreted as the constraint for the chosen optimisation algorithm.

II. Optimisation Algorithms in Architectural Layout Design

The main concern in architectural spatial layout design is finding a viable location for a set of interrelated objects. Also, to fulfill all the design needs and maximise design quality in terms of design preferences. There are two automated optimisation algorithms used in the research of Michalek [3] which are geometry and topology algorithms. The former will work as optimising geometry for large problems, the latter will build on top of the geometry algorithm to search for the feasible topology alternatives and also find the topology that generates the best geometrical layout. The main reason of this research been chosen is because of this new formulation of optimisation in geometry and topology can make it possible to incorporate the control of human decision-making into the process.

Besides, spatial layout is also one of the important architectural design tasks. The spatial layout that needs in architectural design will not have a fix solution and it has to meet some criteria. However, the criteria used still not satisfactory enough for a design in most cases due to multi-objective considerations to be fulfilled individually. The problems that related to multi-objective are seem to be complicated and Genetic Algorithm (GA) are often used to solve and handling complex optimisation problems in diverse applications [4]. GA is one of the most suitable heuristic search algorithm for architectural space layout design by means of a simulated design exercise [5].

III. Genetic Algorithm Works Together With Constraint

GA is a search technique for optimisation or a method of problem solving. So, it might not provide a desired solution for some cases like architectural design, floor planning, economic etc. In order to get the more desire and optimal solutions, GA offers an feasible result to the problem by permitting various constraints to compete as the procedure evolves towards an optimum arrangement that meets those constraints [8]. In addition, designer can use the computational power of computers to help them to resolve some complex interactions between multiple factors and under multiple constraints, it can produce some surprise solutions.

In the field of architectural design, there are a lot of constraints that we have to follow during the optimisation in order to produce desire solutions. The GA can be implemented to optimise the solutions and the penalty functions specific to the problem at hand . The right penalty parameters are needed in penalty function to obtain the feasible solutions. However, the research with title of “An efficient constraint handling method for genetic algorithms” [9] is able to develop a constraint handling mothed that based on penalty function approach which does not require any parameter. In addition, this could also aid GAs with the proposed constraint method have repeatedly found solutions closer to the true optimal solutions earlier than GAs. The time consumption of the process can also be reduced by using this method.

From the literature obtained, there are many ways to obtain an optimised solution in solving the space layout problem. In those many variations, each of them has their own pros and cons. Implementing GA in solving optimisation problems helps because it can solve problems with multiple solutions. Since the problems of architectural layout design do not have the absolute solutions to solve, we think that implementation of GA in architectural layout design optimisation will have higher probability to get the optimal solutions.

GA is an adaptive heuristics algorithm based on the biological evolutionary ideas of natural selection and genetics. It is mimic the survival of the fittest among individuals over repeated generation for solving a problem.

IV. Methodology

The proposed methodology is to include most of the operators of GA such as initialisation, selection and crossover. These operators are used to search the optimal position of objects or furnitures during the simulation of spatial layout design.

The fittest solution is defined by its final fitness value. Hence, suitable fitness function to filter the unnecessary outcome from the population of the GA is developed. The possible outcome with highest fitness value will undergo crossover and produce the new outcome which probably closer to the users’ desire outcome. Some constraints are needed intend to produce an optimal outcome. In this research, the fitness function value is determined by calculation the non-overlapping ratios.

A more details implememtation of each operators and fitness function is described in the next section.

A. Initialisation

Generally, initialisation is very important as it need a first population to undergo the evolution through the generation. The first population is produced by randomly generate hundreds or thousands of possible outcomes. The individuals in the population are then will go through a process of evolution.

B. Selection

The process of selection in GA will take over when the process of the initialisation is finished. Before the selection is started, every single individual will be assigned a fitness value which is calculated or processed by a fitness function. The fitness function will be discussed in detail later. Individual with the highest fitness value will then be selected and allowing them to pass on their genes to the next generation.

C. Crossover

Two individuals with the highest fitness value are chosen from the population will then undergo the process of crossover. It is a process that mating and recombining the two selected individuals also known as parents to create an even better individual and it is also known as new offspring. This process will repeat until the new offspring is fulfill the criteria of termination.

During the crossover process, we have to make sure that all the object that we insert into the floor plan will be shown and in the correct position. For example, the dimension of a table is 3x2 and it is still remained the 3x2 dimension after the process of crossover is occurred. It cannot left only 2x2 and the overlapping section is been replaced by the other object.

D. Fitness Function

Fitness function plays an important role in genetic algorithm. It is the crux that can decide whether the particular genetic algorithm is workable in solving problem or not. In spatial layout design, we concern about the overlapping of the object and also some of the constraints. So, the ratio of overlapping object and non-overlapping object will be used as the main reference of building the fitness function. The basic constraint of housing design will also be use as the additional reference in order to build a more precise fitness function.

E. Implementing GA in Spatial Layout Design

By using the operator that discuss above, we would like to implement them into our problem-solving method. The floor plan will be represented in the array form. In the terminology of the GAs, population is a collection of several alternative solutions to a given problem. Each individual in the population is expressed in the form of a sequence of a number or string which is almost the same thing as array. For example:

```
0 0 0 0 0
0 0 0 0 0
0 0 0 0 0
0 0 0 0 0
0 0 0 0 0
```

Above shows the aerial view of 5x5 dimension floorplan in form of 2D array. The “0” in the floorplan is represent the empty space and not occupy by any of object.

The initialisation process will take place by generating the random possible outcome.

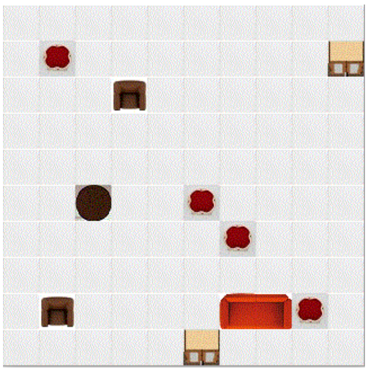
```
0 T T 0 0
0 T T 0 0
0 T T 0 0
0 X 0 0 0
0 0 X 0 0
```

Random possible outcomes with be generated as the example shown above, “T”s are represented as the Table with dimension of 3x2 and “X”s represented the overlapped are occurred at those particular position.

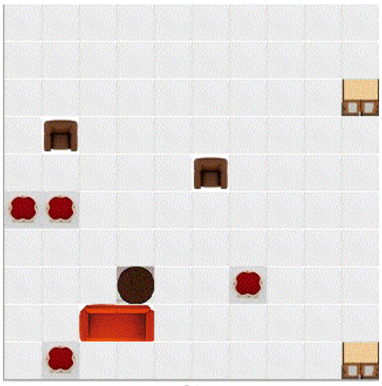
The main purpose of the research is to provide the optimal solution that without the overlapping occurred. The process will then take place by the selection. For each generation, individuals with highest fitness value are selected from the population for reproduction. A fitness value is assigned based on the ratio of the non-overlapping to overlapping in the floorplan. Crossover process is taking place whenever a pair of individuals are selected from the population. Mating of two individuals will produce the higher fitness value of new offspring leading to optimization. The process will repeat until the criteria of termination is fulfilled.

V. Results

Figure 1 shows the possible outcome of the Genetic Algorithm optimization system. This is a preliminary outcome as it only applies the fitness function to calculate the fitness values of non-overlapping object in the particular space.



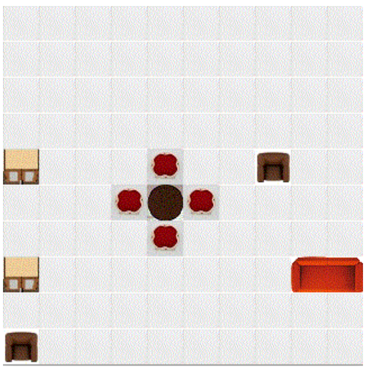
(a)



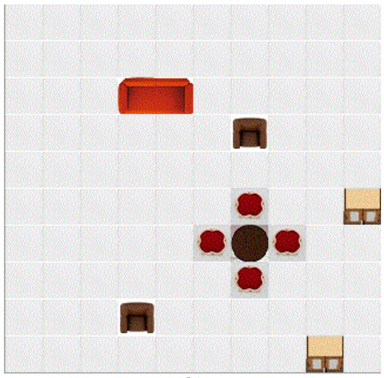
(b)

Figure 1: The possible outcome of the Genetic Algorithm optimization system

After the fitness function of calculating the correct position of object is applied, the outcome is obviously different from the previous outcome that only applies the fitness function of calculating the non-overlapping object. The position of the table with the chair has been corrected in the Figure 2.



(a)



(b)

Figure 2: Position of the table with the chair that has been corrected

The number of generations for the second outcome is 3363 and 3701 generations respectively which is much higher compared to the number of generations for the first outcome which are only 385 and 73 generations respectively. The main reason is the second outcome has undergone the crossover and mutation process to fulfill the criteria of the fitness function in order to increase the fitness value until it reaches the maximum value.

VI. Conclusion

In this paper, a new optimal technique to solve the problem in spatial layout design by using GA is proposed. GA often used to solve complex optimisation problems in diverse applications. Also, suitable to solve design optimisation problems in the architectural floor planning and as algorithm, it is far better than the traditional optimisation methods.

Spatial layout optimisation is an idea where it will optimised spaces of different layouts from the smallest of floor planning, to average like town planning and to the biggest of projects such as geographical planning. Implementing GA in the domain of spatial layout design enables the best solution to be produced for the best optimisation, giving the spatial layout a better arrangement that yet still follow a certain design standard. The guarantee near-optimal solution is resulted from the involvement of various GA's operators. The first operator is the initial operator that populated preliminary population formation and generated random population and inputs. The second operator is the selection operator that choosed the fittest outputs and fitted the contraints best. Lastly, the third operator is the crossover operator that combined the genes from the two fittest outputs to form a new offsprings. Thus, the new offsprings have a better combo-genes compared to their parents.

A non-overlapping object ratios as the fitness function is proposed in this research. The non-overlapping values can be used to evaluate how "good" is the generated solution relative to other solutions. In a real floor plan design practice, it is not realistic to have two furnitures overlapped to each others. For example, a table stack on top of the chair is not a realistic and produced an odd layout. Hence, using non-overlapping ratios as the fitness function is a sensible choice. In this research the highest the fitness value the better the solution.

The next stage is to run the simulations using the proposed method starting with a small layout (10-by-10 cell grids) and a few objects inside. Then, the generated fitness values will be statistically analyse. Another possible future works is to implement different optimisation algorithms and compared with the GA method.

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