Evolutionary Optimization of Residential Floor Plans

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1 Research Topic Title

Evolutionary Optimization of Residential Floor Plans

2 Research Topic Summary

Residential floor plan design is a complex and challenging task that requires careful consideration of various factors, such as room sizes, adjacencies, and orientations. Traditional methods of floor plan design are often time-consuming and labor-intensive, leading to suboptimal solutions. Evolutionary algorithms have been proposed as a promising alternative for optimizing floor plans, as they can efficiently explore the design space and generate high-quality solutions. This project aims to develop a new method for optimizing residential floor plans using evolutionary algorithms and address some limitations of previous research. The proposed method will involve the application of evolutionary algorithms to generate and evolve floor plans based on a novel representation scheme. The fitness of each floor plan will be evaluated based on objective criteria (e.g. energy consumption) and subjective criteria (e.g. privacy, comfort, practicality, convenience). The performance of the proposed method will be evaluated using a set of benchmark problems and compared with existing approaches. The results of this project will contribute to the field of residential floor plan design and provide valuable insights into the application of evolutionary algorithms to architectural design problems.

3 Introductory Background

Residential floor plan design is a critical aspect of architectural design that involves the layout of rooms, corridors, and other spaces within a building. The design of a floor plan can have a significant impact on the functionality, aesthetics, comfort, ventilation and energy efficiency of a building. Traditional methods of floor plan design are often based on manual sketches or computer-aided design (CAD) tools, which can be time-consuming and labor-intensive. Moreover, these methods may not always produce optimal solutions, as they rely on the intuition and experience of the designer.

Evolutionary algorithms have been proposed as a promising alternative for optimizing floor plans, as they can efficiently explore the design space and generate high-quality solutions. Evolutionary algorithms are a class of optimization algorithms inspired by the process of natural selection. They work by maintaining a population of candidate solutions (individuals) and iteratively applying genetic operators (e.g. crossover, mutation) to generate new solutions. The fitness of each solution is evaluated based on a predefined fitness function, which measures how well the solution satisfies the objectives of the optimization problems.

4 Literature Review

Previous research has explored the application of evolutionary algorithms to optimize residential floor plans. Brintrup et al. [1] compared three interactive genetic algorithms (i.e., sequential IGA, multi-objective IGA, parallel IGA) on a multi-objective floor planning task, and found that the multi-objective IGA provides more diverse results and faster convergence for optimizing floor plans. They developed interactive evolutionary algorithms that allow designers to incorporate their preferences and constraints into the optimization process. This method has shown promising results in generating floor plans that meet both functional and aesthetic requirements.

It was found that proportional roulette wheel selection is the best parent selection method for the mating pool, and k-point crossover is the most effective for fitness evolutionary improvement [3]. Combining evolutionary algorithms with greedy-like algorithms can help find near-optimal solutions in Automated Floor Plan Generation (AFPG), though it is a simplified model of multi-objective optimization by linear composition of the partial evaluation functions [5]. Subramanian et al. [6] used a genetic algorithm with KD tree models in a web application to generate floor plans for even non-expert users.

Wang and Duan [8] tried to optimize floor plan design by focusing on energy consumption and consumer satisfaction, proving that the preferences of different types of consumers differed significantly. Therefore, different evaluation criteria are needed for satisfying different family types [8]. The quality and efficiency of residential floor plan design can be improved by combining Monte Carlo tree search algorithm (MCTS) and particle swarm optimization (PSO) [10]. The MCTS algorithm takes human experience into consideration so that it can compress the search space and improve the efficiency of the search process [10]. The PSO algorithm can handle continuous variables and is suitable for optimizing the size of rooms due to parallel processing [10].

Enengy consumption, probable uniformity (PU), and spatial useful daylight illuminance (sUDI) are three objectives that are considered in the optimization process using NSGA-II algorithm, and the results show that the NSGA-II algorithm can provide a set of more sustainable floor plans that requires less computational power and time [2]. Reliable metrics for evaluating the amount of light and the uniformity of light are tested in the optimization process, and can avoid unwanted convergence because they restrict each other [2].

Furthermore, the integration of machine learning techniques with evolutionary algorithms has gained attention in recent decades. For example, Wang [7] proposed a hybrid approach that combines a genetic algorithm with a neural network to predict the fitness of candidate solutions. This method significantly reduces the computational cost of evaluating large populations and accelerates the optimization process.

Overall, the literature indicates that evolutionary algorithms, particularly when combined with other optimization techniques and machine learning methods, offer a powerful tool for optimizing residential floor plans. These approaches not only improve the efficiency and quality of the designs but also provide flexibility in accommodating various design preferences and constraints.

5 Aims, Objectives of the Project

This project aims to develop a new and efficient method for optimizing residential floor plans using evolutionary algorithms, and address some limitations of previous research. The main objectives of this project are as follows:

- Implement an efficient initialization strategy for the generation of the initial population.
- Develop a more robust evolutionary optimization framework tailored to residential floor plans.
- Propose a novel representation scheme for residential floor plan layouts.
- Conduct a comprehensive comparison of the proposed method with existing approaches to evaluate its performance.

6 Methodology

The methodology of this project involves the application of evolutionary algorithms to optimize residential floor plans. The process will be divided into several key stages: initialization of the population, representation of the floor plan, design of the evolutionary optimization framework, and performance evaluation. These stages are outlined below.

6.1 Population Initialization

The first step in the evolutionary process is to generate an initial population of residential floor plans. An efficient initialization strategy will be employed to ensure diversity within the population while adhering to basic architectural constraints, such as room adjacency and size. Specifically, it contains 2 stages: 1. Locate room positions (red dots in Figure 1), 2. Locate wall positions based on room sizes (blue lines in Figure 1) [9].

6.2 Representation of Floor Plans

Residential floor plans will be represented using a novel structure, parse tree [4], that encodes the spatial relationships between rooms, such as adjacency and sizes. As shown in Figure 2, the room sizes and adjacencies after split are the same as the original root. This representation will be designed to allow for easy manipulation by evolutionary operators (e.g. crossover and mutation) while preserving architectural feasibility and obeying relevant constraints.

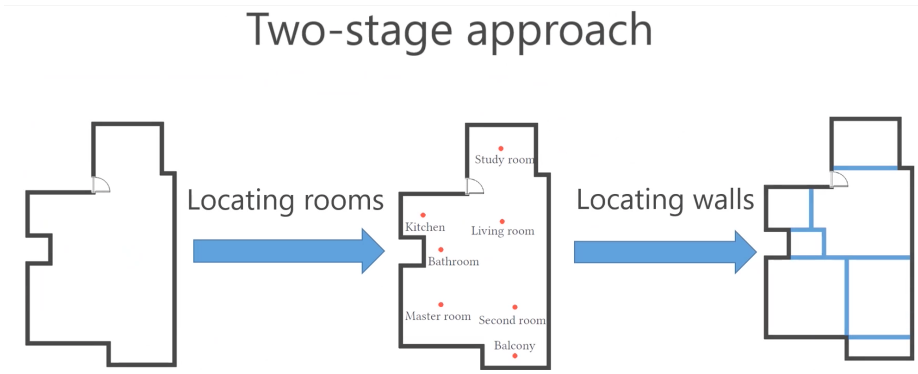


Figure 1: Population initialization. Figure 2 of Wu et al. [9]

Figure 2: Parse tree representation of floor plans. Figure 3 of Lee and Stenger [4]

6.3 Evolutionary Optimization Framework

The evolutionary optimization framework will be based on a standard evolutionary algorithm, with modifications to better suit the characteristics of floor plan design. The selection process will prioritize diversity to avoid premature convergence, while the crossover operator will combine features of two or more floor plans to produce offspring with novel characteristics. Mutation will introduce small random changes to further explore the design space. The fitness of each floor plan will be evaluated based on objective criteria (e.g. energy consumption), subjective criterion (e.g. privacy, comfort, practicality, convenience), and compliance with architectural standards. If necesssary, more than one evolutionary algorithm will be used in the process of optimizing the floor plan. For example, Monte Carlo tree search algorithm (MCTS) handles discrete variables and particle swarm optmization (PSO) deals with continuous variables [10].

6.4 Fitness Function Design

The fitness function will evaluate each floor plan based on several criteria: 1. Objective criteria: energy consumption. 2. Subjective criteria: privacy, comfort, practicality, convenience. The energy performance evaluation can be achieved by simulation in Topologic [8]. The subjective criteria can be evaluated by a group of human evaluators, shown as Table 1.

The straight distance between the geometric centers of room m and n is defined as:

$$\mathrm{dis}(m, n) = \sqrt{(x_m - x_n)^2 + (y_m - y_n)^2}$$

The percentage of area of R to the interior area of the floor plan is defined as:

$$\% \text{ of } R = \left(\frac{\text{Area of } R}{\text{Interior Area of Floor Plan}} \right) \times 100\%$$

The efficiency rate of a house is defined as the percentage of interior area to the total area of the floor plan:

$$\text{Efficiency Rate} = \left(\frac{\text{Interior Area}}{\text{Total Area}} \right) \times 100\%$$

The walking distance along 0- or 90-degree lines between the geometric centers of room m and n is defined as:

$$\mathrm{DIS}(m, n) = |x_m - x_n| + |y_m - y_n|$$

The proposed method will be implemented in Python. The optimization process will be carried out in two stages: initialization and evolution. The initialization stage will involve generating an initial population of floor plans using a novel strategy. The evolution stage will consist of iteratively applying genetic operators to the population to produce new generations. The fitness of each individual will be evaluated using a fitness function that considers various factors such as the number of rooms, room sizes, and room adjacencies. The

Evaluation indicators of floor plans of MURBs.

First-level indicator	Second-level indicator	Type	Reference
C1 Privacy	C11 dis (MBR, BR)	Positive	Gao et al. (2013)
	C12 dis (MBR, BA)	Positive	Kong (2013)
C2 Comfort	C21 Orientation of living room (0: north; 1: south)	Positive	Gao et al. (2013)
	C22 Light in dining room (0: dark; 1: bright)	Positive	Gao et al. (2013)
	C23 Ventilation (Ratio of width to depth of floor plan)	Positive	Gao et al. (2013)
	C24% of south-facing rooms	Positive	Gao et al. (2013)
C3 Practicality	C31% of hall	Negative	Kong (2013)
	C32% of balcony	Positive	Kong (2013)
	C33 Efficiency rate of a house	Positive	He (2020)
C4 Convenience	C41 DIS (BR, BA)	Negative	Gao et al. (2013)
	C42 DIS (BA, BAL)	Negative	Gao et al. (2013)

Note: "dis (m, n)" means the straight distance between the geometric centers of room m and n.
"% of R″ means the percentage of area of R to the interior area of the floor plan.
"Efficiency rate of a house" means the percentage of interior area to the total area of the floor plan.
"DIS (m, n)" means the walking distance along 0- or 90-degree lines between the geometric centers of room m and n.

Table 1: Evaluation indicators. Table 2 of Wang and Duan [8]

optimization process will be repeated for a specified number of generations or until a termination criterion is met. The performance of the proposed method will be evaluated using a set of benchmark problems and compared with existing approaches.

7 Significance

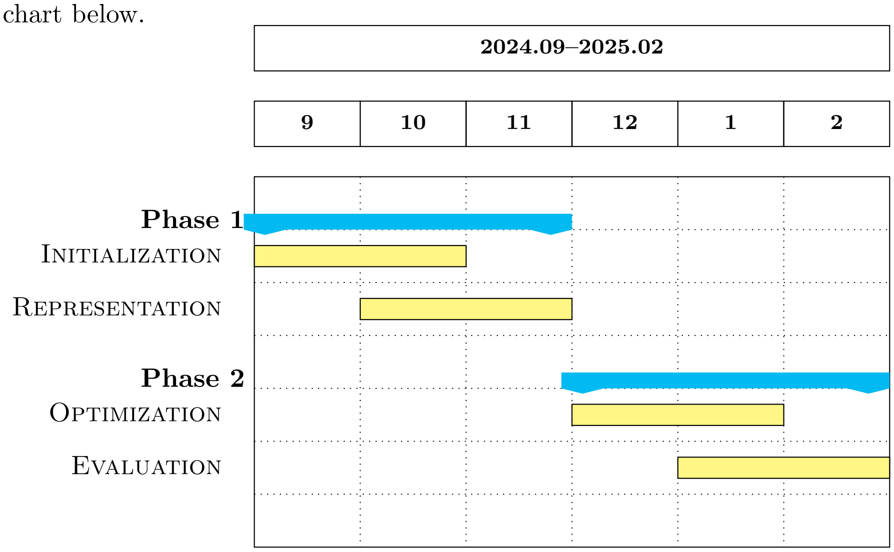
The proposed research method will contribute to the field of residential floor plan design by providing a new and efficient approach to optimizing floor plans using evolutionary algorithms. The method will address some limitations of previous research and offer valuable insights into the application of evolutionary algorithms to architectural design problems. The results of this project will be of interest to architects, designers, and researchers working in the field of architectural design and optimization. The proposed method has the potential to improve the quality, diversity and efficiency of residential floor plan design and lead to the development of innovative and sustainable building designs.

8 Research Plan

My research plan consists of four main phases:

- Phase 1
  1. Population initialization
  2. Solution representation
- Phase 2
  1. Evolutionary optimization
  2. Solution evaluation

Each phase will involve specific tasks and activities that will be carried out over a period of 6 months. The timeline for the research plan is shown in the Gantt chart below.



9 Plagiarism Declaration

I hereby declare that this submission is my own work and to the best of my knowledge, it contains no material previously published or written by another person, except where due to acknowledgment is made. Furthermore, I believe that it contains no material which has been accepted for the award of other degree or diploma in any university or other tertiary institutions.

10 References

[1] A. M. Brintrup, H. Takagi, and J. Ramsden. Evaluation of sequential, multi-objective, and parallel interactive genetic algorithms for multi-objective floor plan optimisation. In F. Rothlauf, J. Branke, S. Cagnoni,

E. Costa, C. Cotta, R. Drechsler, E. Lutton, P. Machado, J. H. Moore, J. Romero, G. D. Smith, G. Squillero, and H. Takagi, editors, *Applications of Evolutionary Computing*, pages 586–598, Berlin, Heidelberg, 2006. Springer Berlin Heidelberg.

[2] B. Chaichi and A. Andaji Garmaroodi. Multi-objective optimization of a residential zone by proposing appropriate comfort factors using none dominated sorting genetic algorithm. *Journal of Building Engineering*, 86:108842, 2024.

[3] A. de Almeida, B. Taborda, F. Santos, K. Kwiecinski, and S. Eloy. A genetic algorithm application for automatic layout design of modular residential homes. In *2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, pages 002774–002778, 2016.

[4] P. K. Lee and B. Stenger. Shape-based floor plan retrieval using parse tree matching. In *2021 17th International Conference on Machine Vision and Applications (MVA)*, pages 1–5, 2021.

[5] M. Nisztuk and P. B. Myszkowski. Hybrid evolutionary algorithm applied to automated floor plan generation. *International Journal of Architectural Computing*, 17(3):260–283, 2019.

[6] R. Subramanian, T. DheenaDayalan, T. Badhrirajan, C. Dhinakaran, C. Devakirubai, and R. R. Sudharsan. An automated house plan generator leveraging genetic algorithms. In *2021 International Conference on Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA)*, pages 1–6, 2021.

[7] L. Wang. A hybrid genetic algorithm–neural network strategy for simulation optimization. *Applied Mathematics and Computation*, 170(2):1329–1343, 2005.

[8] T.-K. Wang and W. Duan. Generative design of floor plans of multi-unit residential buildings based on consumer satisfaction and energy performance. *Developments in the Built Environment*, 16:100238, 2023.

[9] W. Wu, X.-M. Fu, R. Tang, Y. Wang, Y.-H. Qi, and L. Liu. Data-driven interior plan generation for residential buildings. *ACM Trans. Graph.*, 38(6), Nov. 2019.

[10] S. Yan and N. Liu. Computational design of residential units' floor layout: A heuristic algorithm. *Journal of Building Engineering*, 96:110546, 2024.