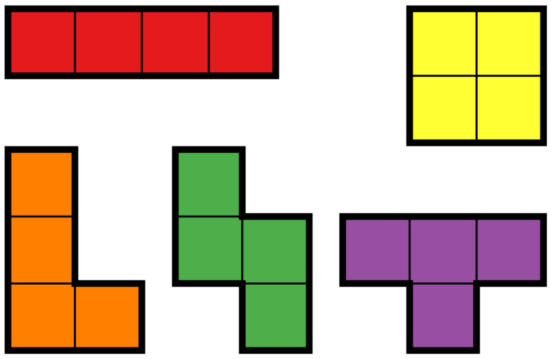
INF219 – COWI Research



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GitHub Repository

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1 Summary

Click me: for the full repo

This project considers techniques for placing light fixtures in any given room, minimizing the amount of lights used whilst still being compliant with regulatory and aesthetic requirements.

There are many different approaches to such a challenge. For instance, COWI presented a genetic algorithm/reinforcement learning ML-based solution. Their approach entailed maximizing coverage area while maintaining a pattern by penalizing variations in x/y coordinates.

We chose to take a different approach, using Linear Programming instead. The main reason behind this choice is the guaranteed optimality involved in such a solution. Using a solver, we are able to find the single most mathematically optimal solution that satisfies all constraints, given that a solution exists.

In addition to the optimality, we are also presented with several other advantages using the LP approach. The deterministic nature of our solution ensures that given the same inputs and constraints, we always get identical, reproducible results — eliminating the randomness inherent in genetic algorithms. This consistency is particularly valuable in professional settings where repeatability is essential.

Our LP formulation also offers greater transparency and explainability, making it clear exactly what we're optimizing for and what constraints we're satisfying. For typical room dimensions, the LP solver finds optimal solutions relatively quickly, without requiring the multiple generations of evolution that genetic algorithms need. This efficiency translates to faster design iterations and project delivery. The precise constraint handling in our approach allows for explicit modeling of critical requirements like minimum light levels and fixture spacing. Rather than approximating these through penalty functions as in the genetic algorithm approach, we incorporate them directly into the mathematical model. Finally, our solution offers straightforward adaptability to changing requirements. The LP model parameters can be easily adjusted to meet different regulatory standards or design preferences without needing to retrain an entire ML model. While the ML-based approach might offer advantages in terms of continuous learning from historical data, our LP solution provides immediate, verifiable results with mathematical guarantees—a critical factor when dealing with safety-related regulatory compliance in building design. This becomes a bigger deal if we choose to also incorporate positioning of a sprinkler system.

2 Motivation and Introduction (Thone)

3 Mathematics (jakob se over)

In this section, we will discuss the mathematical model behind the program.

3.1 Sets and Indices

$$G = \{(x, y) \mid (x, y) \in \mathbb{R}^2\} \quad \text{(Grid points for potential circle placement)} \tag{1}$$

$$A = \{(x, y) \mid (x, y) \in \mathbb{R}^2\} \quad \text{(Area cells for measuring coverage)} \tag{2}$$

3.2 Decision Variables

$$z_{x,y} \in \{0, 1\} \quad \forall (x, y) \in G \quad \text{(Binary variable for circle placement)} \tag{3}$$

$$c_{x,y} \geq 0 \quad \forall (x, y) \in A \quad \text{(Continuous variable for cell light level)} \tag{4}$$

3.3 Parameters

$$\alpha_{(x_g,y_g),(x_a,y_a)} \geq 0 \quad \text{(Coverage value from grid point to area cell)} \tag{5}$$

$$L_{\min} \geq 0 \quad \text{(Minimum required average light level)} \tag{6}$$

$$S_{\min} \geq 0 \quad \text{(Minimum required spacing between circles)} \tag{7}$$

$$A_g \subset A \quad \text{(Set of area cells within grid cell } g \in G\text{)} \tag{8}$$

3.4 Objective Function

$$\min \sum_{(x,y) \in G} z_{x,y} \quad \text{(Minimize total number of circles)} \tag{9}$$

3.5 Constraints

$$c_{x_a,y_a} = \sum_{(x_g,y_g) \in G} \alpha_{(x_g,y_g),(x_a,y_a)} \cdot z_{x_g,y_g} \quad \forall (x_a, y_a) \in A \tag{10}$$

$$\sum_{(x_a,y_a) \in A_g} c_{x_a,y_a} \geq L_{\min} \cdot |A_g| \quad \forall g \in G \text{ where } |A_g| > 0 \tag{11}$$

$$z_{x_1,y_1} + z_{x_2,y_2} \leq 1 \quad \forall (x_1, y_1), (x_2, y_2) \in G \text{ where } \max\left(\frac{|x_1 - x_2|}{\text{grid\_size}}, \frac{|y_1 - y_2|}{\text{grid\_size}}\right) \leq S_{\min} \tag{12}$$

3.6 Constraints explainations

10. Defines how the light level for each area cell is calculated
11. Ensures that each grid cell receives adequate light
12. Prevents lights from being placed too close to each other
13. TODO add neigh constraint

4 Execution

In this section we will shine some light on how we chose to solve the main problem – finding the optimal solution via a generic algorithm for placing light fixtures in any room of any size.

4.1 Method (jakob)

As previously mentioned, a genetic algorithm/RL approach was presented to us. Although this can be a good solution in some cases, we found out that this method does not provide heuristics that are sufficiently effective or efficient for approximating the optimal solution.

Our approach to optimizing light fixture placement employs linear programming (LP), a powerful mathematical optimization technique that allows us to find the exact minimum number of fixtures required while satisfying all regulatory and aesthetic constraints.

The problem is formulated as a binary integer linear program where each potential fixture location is represented by a binary decision variable. The objective function minimizes the total number of fixtures, subject to a set of constraints that ensure adequate light coverage and appropriate spacing between fixtures.

The room is first resized into a smaller polygon. The reason for this is so that we can avoid considering not placing lights near the walls. This is a relatively easy and efficient way of minimizing computational cost as we don't need to define this in the constraints. Next up, we discretize the room into a grid, where each grid point represents a potential fixture location. A finer grid of area cells is then used to evaluate light coverage with precision. For each area cell, we calculate the light contribution from all potential fixture locations, creating a coverage model that accounts for light falloff with distance.

Two primary constraint types govern our solution; coverage constraints ensure that each area maintains at least the minimum required light level (lux) specified by regulations, while spacing constraints enforce a minimum distance between fixtures to create aesthetically pleasing and practically functional layouts.

Unlike heuristic approaches such as genetic algorithms that approximate solutions, our LP formulation guarantees finding the mathematically optimal solution whenever one exists. This mathematical certainty is particularly valuable in contexts where regulatory compliance must be definitively demonstrated.

The model's flexibility allows for straightforward parameter adjustments to accomodate different regulatory standards or design preferences. By simply modifying the minimum lux parameter or the fixture spacing requirement, the model can be adapted to various building types and usage scenarios without requiring findamental changes to the underlying optimization approach.

Implementation is achieved using the PuLP library in Python, which interfaces with powerful LP solvers capable of handling the binary integer programming challenges in the problem space.

4.2 What we tried: (hanna) (talk about our shortcomings)

5 Experiments (TBD)

5.1 Light distribution plot

5.2 Small room

5.3 Large room

5.4 Runtime Discussion

6 Discussion (Håvard)

6.1 Potential Improvements

6.1.1 Caching

7 Conclusion (Hermann)