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# A Multistage Methodology Approach for Constraints Prioritisation of Facility Layout Problem (FLP) in Enhancing the Performance of Building Energy Efficiency

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**ABSTRACT**

Facility Layout Problem (FLP) is gaining increasing attention among researchers; it is a term relating to the poor layout of facilities as a significant contributing factor of poor performance. FLP is of paramount importance when determining inefficiencies in large room layouts, such as a library building, since the building's layout closely influences air distribution and impacts on human comfort. Thus, this can lead to unnecessary high energy use to mitigate any inefficiencies. This problem is classified as an NP-hard problem (non-deterministic polynomial-time hardness), considering the various factors influencing thermal factors and layout design. However, previous research shows a lack of consideration of FLP for large rooms. It is identified that various types of constraints are considered in the layout problem literature, and penalty-based constraints are often being prioritised by mere human judgement and intuition. Hence, the accuracy of the objective decision-making is questionable. Therefore, this study proposes a multi-stage methodology to determine the weight of each constraint for FLP by using a multi-criteria decision making (MCDM) method specific to a library building as a case study exemplar. This study's main focus is to determine penalty based constraints in meta-heuristic approaches for the effective use of FLP. This study concludes by advocating that the proposed methodological approach can be used to identify the most significant constraints in FLP.

***Keywords:***
Facility Layout Problem, Multi-criteria decision making, Optimisation approach, Penalty function, Constraints prioritisation

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## 1. Introduction

The placement of facilities within rooms, commonly referred to as the Facility Layout Problem (FLP), has successfully solved many ills in terms of productivity, energy efficiency etc., within many discipline areas such as in management and industrial engineering [1]. However, recent studies have

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identified grave concern regarding a buildings' energy conservation, as a poor layout can contribute to unnecessary consumption of a significant amount of energy. Energy conservation is an important goal to address the environmental challenge, and a great deal of research and practical changes are being made to root out causes [2-4]. Thus, this research advocates the use of FLP in an attempt to determine other possible parameters to reduce the building's energy use.

According to Qiao *et al.* [5], the facility's layout plays a contributing factor in the air circulation for large rooms. Layout of facilities can cause differing temperatures in different areas, thus, impacting on human comfort. In many cases, human thermal variations caused by FLP are not often factored in the planning process [6,7]. Qiao *et al.* [5] have demonstrated the impact of layout on energy efficiency by considering the thermal sensation rate (TSR) in a large public room by controlling the air-conditioner control (ACC) system, and therefore, FLP must be considered as a contributing factor for energy efficiency.

In a huge area, such as a library, the location of bookshelves for instance, can change air flow patterns irrespective of the room's ACC system's technical specification or natural ventilation pattern prediction. Within the scope of FLP, there have many factors that can affect the precision of results in any research field. The same goes for energy use within buildings; the facility layout inside a large room can be impaired by human decision or environmental factors. In the same vein, many of these factors can in turn be used to directly influence improved energy efficiency. Thus, there appears to be an open gap in the study of the prioritisation of constraints for FLP in large room planning. Therefore, this research aims to propose a multistage methodology to prioritise the penalty-based constraints for FLP using the MCDM (multi-criteria decision-making) method. The penalty function is to be used for the meta-heuristic approaches in FLP optimisation problems for large room configuration. Meanwhile, this problem can be classified as an NP-hard (non-deterministic polynomial-time hardness) problem. Penalty function is implemented in order to increase the accuracy of facility layout (FL) constraints prioritisation in an optimisation approach. In practice, typically, amendments to planning have largely been governed by human judgment and intuition alone for prioritisation procedures [8,9].

Note: this study is only limited to prioritising the objective function's constraints using the MCDM method and presents the findings through a case study exemplar project. Under the MCDM method, each alternative or constraint's weight is identified before prioritisation is administered. Subsequently, the outcome of this study is proffered to be utilised for future studies on energy optimisation in FLP.

## 2. Methodology

This section articulates the methodological approach for the application of FLP in a large room problem as a case study exemplar. Note, the term 'criteria' will henceforth be used in replacement of the term 'constraint' as this is common in the application of MCDM. However, both terms have the same meaning in this context.

### *2.1 Case study approach*

The case study technique will be employed to analyse real-life phenomena, which enables a deep insight into the research issue's complex conduct [10]. The application of this research methodology also benefits from using multiple approaches for data collection purposes, whether from one or more parties (people, community or organisation) [11].

Case study methods can define the information in the real-life condition and direct the researcher to illustrate the complexity of a real-life scenario [10]. The case study can also deal with many apparent records, interviews and observations [12]. Then, before it is applied in the actual research area, the work type should follow the case study process requirements. The conditions are the work must be a qualitative approach with a small sample size [11,12], clinical and ethnographic type, characterise as process-tracing [13], the research investigates the properties of a single case [14], and a single phenomenon only.

Thus, this study seems fit to the characteristics of the case study approach. The main objective is to prioritise the facility layout criteria of the library building. In-depth research needs to be done through several approaches, including interviews, observations, literature and others. The data collection process under qualitative methods uses a small sample size because it only involves library staff and technical people. Since researchers have just introduced this study, interview sessions are very important to select the most appropriate criteria.

In literature, the case study method has been often used since the past in solving facility layout problems [15-19]. There are four steps in the case study research approach suggested by Yin [11]. The first three steps include a) planning, b) conducting, and c) analysing a case study, while the final stage, d) developing the conclusions, recommendations and implications. This study follows the steps as indicated by Yin [11].

### *2.2 Mathematical Model*

#### *2.2.1 Multi-criteria attribute decision making (MADM)*

The MADM method usually involves a set of discrete parameters and several predefined alternatives. The MADM approach's function is to select the right alternative among the list of alternatives to solve the existing problem. Also, the MADM method specifies the process of handling attribute information to ensure that selection is achieved.

Table 1 illustrates the decision matrix in the MADM method; it contains four important parts: alternatives, criteria, significant weights of each criterion, and alternative performance values of each criteria. By laying out the decision-making method, decision-makers need to calculate and determine the best solution among the given set of alternatives. Note that all the table components should use the same unit of analysis as to ensure all criteria can be appropriately compared [20].

**Table 1**
Decision-making matrix of a MADM model

| **Alternatives** | **Criteria** | | | | | |
|---|---|---|---|---|---|---|
| | $C_1$ ($w_1$) | $C_2$ ($w_2$) | $C_3$ ($w_3$) | - (-) | - (-) | $C_M$ ($w_M$) |
| $A_1$ | $x_{11}$ | $x_{12}$ | $x_{13}$ | - | - | $x_{1M}$ |
| $A_2$ | $x_{21}$ | $x_{22}$ | $x_{23}$ | - | - | $x_{2M}$ |
| $A_3$ | $x_{31}$ | $x_{32}$ | $x_{33}$ | - | - | $x_{3M}$ |
| - | - | - | - | - | - | - |
| - | - | - | - | - | - | - |
| $A_N$ | $x_{N1}$ | $x_{N2}$ | $x_{N3}$ | - | - | $x_{NM}$ |

### *2.2.2 Weighting criteria approach*

Previous literature (such as in [21-27] suggested many techniques for solving different MCDM problems when faced with weighting criteria. Some of the most popular techniques used is AHP (analytical hierachay process), the TOPSIS (the technique for order of preference), ranking method, SAW (simple additive weighting, VIKOR (vise kriterijumska optimizacija I kompromisno resenje, WSM (weighted sum method), WPM (weighted product model) and others.

According to Odu [28], the ranking method (such as Equal Weight, Rank Sum, Rank Reciprocal and others) is the easiest approach to determine the weight of the criteria arranged from the most importance to the least importance. Barron and Barrett [29] introduced other rank-based methods, namely: Rank Sum (RS), Rank Reciprocal (RR), and Rank-Order Centroid (ROC) methods. Other rank-based methods found in the literature include: Equal Weight (EW), Rank Exponent (RE) [30,31] and Sum-Reciprocal (SR) methods [32]. Although these methods are easy to use, it has a big impact on the field of research because of its advantages especially in urgent situations.

There are several situations that give advantages to the ranking method so that it is often implemented, namely time constraints, consistency requirements, lack of expertise, inaccuracies, incomplete or partial information, insufficient consideration by decision-makers and the capacity to process information. This means that the decision-maker may not be able to provide accurate forecasts of the decision features. Moreover, there are more detailed explanations of why accurate weights' expectation is impractical [29,31,33]. Also, the community of decision-makers has not been able to find a consensus on a set of actual weights, but in such a case, it might be reasonable to assume agreement only via the ranking of weights. Moreover, the other techniques used to weigh the criteria are shown in Table 2.

**Table 2**
The list of other techniques used in weighting criteria

| No. | Weighting criteria techniques | References |
|---|---|---|
| 1. | VIKOR | [34,21-23] |
| 2. | ELECTRE | [35-37] |
| 3. | WSM | [25,38-41] |
| 4. | WPM | [24,41,42] |
| 5. | SAW | [26,27,42] |

Based on the above methods, qualitative and quantitative input is often considered in determining the parameters' weight to achieve a better and more precise weight. Weighting criteria approaches can typically be divided into three groups: subjective, objective, and integrated [28].

Subjective weight assessment is based on professional judgment, and usually, the observers propose a series of questions to decision-makers in order to obtain various perspectives. In objective weighting techniques, the parameter weights are extracted from the knowledge obtained in each criterion using theoretical simulations with no direct input assessment from the decision-maker [43]. The integrated weighting technique is a weighting system combining a variety of subjective and objective weighting methods. It relies on the concept of combining subjective weights based on expert opinion by referring to their skill and experience in the related area, and also, objective weighting where the input obtained from the details of the parameters in a theoretical process [28].

Accordingly, this study's primary focus is to prioritise the facility layout criteria in a library building. Moreover, this study suggests a list of criteria without offering an alternative list. Therefore, the Guaranteed AHP method and ranking method are seen as suitable approaches to solve facility layout criteria rather than the other techniques.

The Guaranteed AHP was introduced by Nazri *et al.* in 2016 [44]. The previous AHP showed some deficiencies where the reassessment process had to be done if inconsistency values were found at the consistency ratio (CR), affecting the initial preference. Then, they suggest some preliminary assessment steps before making pairwise comparisons to get a more consistent CR value. Meanwhile, in this study, Guaranteed AHP and ranking methods are preferred. The reasons for selecting these two methods is the potential to calculate the weight of criteria without alternatives, less use of tools (e.g. questionnaires), and ease of use. Details of both methods have been explained as follows.

**a) Guaranteed AHP**

The guaranteed AHP approach introduced by Nazri *et al.* [44] proposes the pre-evaluation step to achieve a consistent AHP by focusing on the pairwise comparison procedures' basics. Typically, the evaluators need to complete the pairwise comparisons manually that take a certain time and uncertain consistency level. However, the authors suggest a more effective procedure using the rating technique by implementing the same scale of Saaty (scale values from 1 to 9) [45,46]. The proposed approach promises consistent AHP results but is limited to only nine criteria. The process of the Guaranteed AHP method has been described as below:

Step 1: The evaluator needs to rate each criterion's importance using the Saaty scale from value 1 to 9 (Table 3).

**Table 3**
Description of Saaty scale (1-9 scale)

| Intensity of Importance | Definition |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance of the first element over the second element in the pair |
| 5 | Strong or essential importance of the first element over the second element in the pair |
| 7 | Very strong importance of the first element over the second element in the pair |
| 9 | Extreme importance of the first element over the second element in the pair |
| 2,4,6,8 | Intermediate value between two adjacent judgements |
| Reciprocals of the above non-zero numbers | The inverse of the importance (e.g., a value of $\frac{1}{5}$ means that the second element has very strong importance over the first element in the pair) |

Source: Saaty [45] and Chen [46].

Step 2: Translate the rating value into Saaty's AHP-pairwise comparison table $C = [c_{ij}], n \times n$, using the following algorithm.

Assume $N$ as the number of criteria. Let $r_i$ and $r_j$ represented as criterion $i$ and $j$, respectively. Then, $c_{ij}$ which is the pairwise comparison value between criterion $i$ and $j$ will be calculated as follows:

Let $b = r_i - r_j$ (3.1)

If $b > 0$, then $c_{ij} = b + 1$ (3.2)

If $b = 0$, then $c_{ij} = 1$ (3.3)

If $b < 0$, then $c_{ij} = 1/(1 - b)$ (3.4)

Step 3: Calculate the weight of each criterion using the standard AHP-technique in which the criteria weight, $W_{ij}$ can be calculated as follows:

$$W_{ij} = \frac{\sum_{i=1}^{n} c_{ij}}{n} \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix}, \quad (3.5)$$

where $n$ is the total number of criteria.

Step 4: Next, the results of the AHP need to be validated by calculating the consistency ratio ($CR$) shown in the equation below:

$$CR = \frac{CI}{RI}, \quad (3.6)$$

where $CI$ represents the consistency index, and $RI$ represented a random index. $CI$ can be measured through the following formula:

$$CI = \frac{\lambda_{max} - n}{n - 1}, \quad (3.7)$$

where $\lambda_{max}$ represents the maximum eigenvalue of the comparison matrix, and $n$ is the total number of criteria. Meanwhile, the value of $RI$ is related to the dimension of the matrix and will be taken from Table 4.

**Table 4**
Random Index

| **Dimension** | $RI$ |
|---|---|
| 1 | 0.00 |
| 2 | 0.00 |
| 3 | 0.58 |
| 4 | 0.90 |
| 5 | 1.12 |
| 6 | 1.24 |
| 7 | 1.32 |
| 8 | 1.41 |
| 9 | 1.45 |
| 10 | 1.49 |

Source: Saaty [47]

Notice that the $CR$ value must be below or equal to 0.1 ($CR \leq 0.1$) to confirm it as an acceptable comparison result.

**b) Ranking method**

Moreover, the ranking method includes several approaches: the EW, RS, RR, RE, ROC, and SR method. The first five types of techniques are the most frequently used methods by the previous researchers, while the SR method was proposed by Danielson *et al.* in 2016 [32]. Therefore, the mathematical formula for all types of the ranking method has been described below:

1. Equal weight (EW) method:

$$W_j(EW) = \frac{1}{n}, \tag{3.8}$$

where $j = 1,2,3, \dots, n$. $W_j$ represents the weight of criteria, and $n$ is the total number of criteria.

2. Rank sum (RS) weight method [30]:

$$W_j(RS) = \frac{n - r_j + 1}{\sum_{k=1}^{n} n - r_k + 1} = \frac{2(n + 1 - r_j)}{n(n+1)} \tag{3.9}$$

where $r_j$ is the rank of the $j$-th criterion, $j = 1,2,3, \dots, n$.

3. Rank reciprocal (RR) weight method [30]:

$$W_j(RR) = \frac{1/r_j}{\sum_{k=1}^{n}(1/r_j)} \tag{3.10}$$

where $r_j$ is the rank of the $j$-th criterion, $j = 1,2,3, \dots, n$.

4. Rank exponent (RE) weight method:

$$W_j(RE) = \frac{(n - r_j + 1)^p}{\sum_{k=1}^{n}(n - r_k + 1)^p} \tag{3.11}$$

where $r_j$ is the rank of the $j$-th criterion, parameter $p$ describing the weight, $j = 1,2,3, \dots, n$. The value of $p$ can be estimated from the most significant criterion weight or via interactive scrolling. If $p = 0$, the criteria weight will equivalent to the EW result. Meanwhile, if $p = 1$, the criteria weight will be equivalent to RS weight. The steepness of weight distribution will depend on the value of $p$. The bigger the value of $p$, the steeper the graph line.

5. Rank order centroid (ROC) weight method:

$$W_j(RR) = \frac{1}{n} \sum_{k=j}^{n} \frac{1}{r_k} \tag{3.12}$$

The ROC weight procedure is the most stable method [29] as it can estimate the weight criteria by minimizing each weight's maximum error. They propose identifying the centroid of all possible weights maintaining the rank order of objective importance.

6. Sum-Reciprocal (SR) weight method:

$$W_j(SR) = \frac{(1/j)+(\frac{n+1-j}{n})}{\sum_{k=1}^{n}\left[(1/k)+\frac{n+1-k}{n}\right]} \quad (3.13)$$

SR weight method is the combination of rank-sum and ranks common weight method. The authors suggest this strategy can purposefully balance them evenly in an additive mixture while seeing if extreme behaviours can be minimised. However, their research's final results show that SR gives outstanding performance compared to others [32].

### *2.3 Implementation of weighting method for FL criteria*

This section details the implementation of the weighting method in prioritising FL criteria. As explained in Section 2.2.2, two types of weighting methods are selected, including Guaranteed AHP and ranking method, where both techniques do not consider alternative components. Therefore, to briefly describe the mathematical model development process, Fig. 1 shows the overall weighting method process (include Guaranteed AHP and ranking method) for FL criteria prioritisation.

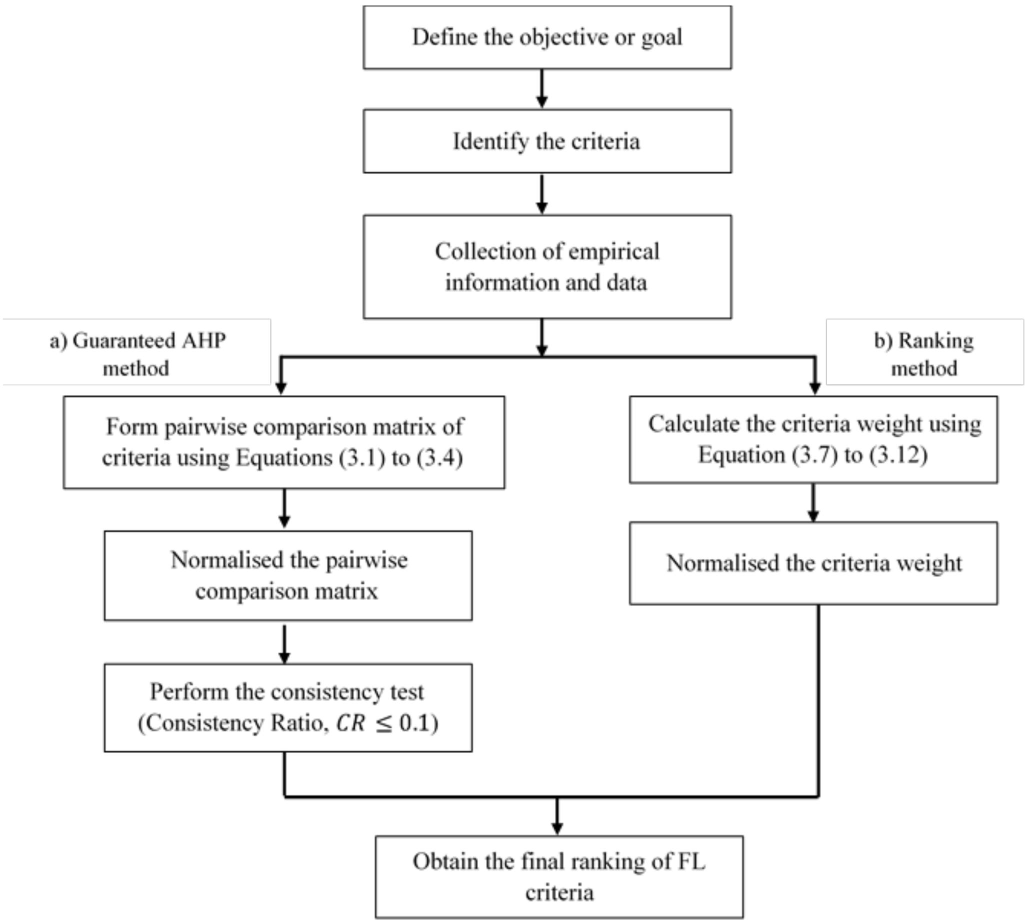


**Fig. 1.** Weighting method process for FL criteria prioritisation

Based on Fig. 1, a decision model for the FL criteria prioritisation can be obtained. Fig. 1 indicates two methods applied, namely AHP Guaranteed and ranking, to assess the final ranking of FL criteria based on the final criteria weight. As mentioned earlier, AHP Guaranteed provides a consistent $CR$ value ($CR \leq 0.1$) with the number of criteria limited to nine criteria only; therefore, only one assessment process is required. It is noted that the $p$ value for the RE method is considered “2” taken from the literature [48,49]. Meanwhile, the details of the calculation will be explained in the next section.

## 3. Discussion and Conclusion

A review on FLP in a large room revealed the need to prioritise FL constraints for further research in the optimisation approaches. FLP in a large room significantly impacts energy consumption as it is closely related to air distribution and user comfort. There have been limited studies on FL constraints prioritisation for penalty functions in optimisation approaches for large room problems such as library buildings. In contrast, the previous studies only use human judgment and intuition for prioritisation procedures. Hence, the accuracy of the objective function is questionable. Therefore, this study presents the multistage of methodology to determine the FL constraints prioritisation for FLP in a large room problem by using the MCDM method.

The case study approach has been used to identify and validate the constraints. The validation process will be confirmed by the decision-makers (DMs) which directly involves in this project. Meanwhile, the data used in this research were collected through literature and semi-structured interviews. Moreover, under the MADM, the weighting method which includes the Guaranteed AHP and ranking techniques is used as a decision model. By using both techniques, the mathematical model of FL constraints has been developed based on the case study result.

In a conclusion, the multistage methodology is able to be successfully be implemented to determine the FL constraints prioritisation for solving the FLP in a large room problem. Then, the performance of the building is assumed can be improved.

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