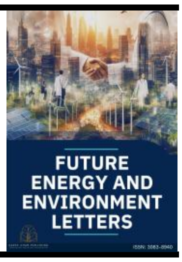
KARYA ILHAM PUBLISHING
CONNECTING MINDS, BRIDGING IDEAS, INSPIRING READERS

Future Energy and Environment Letters

Journal homepage:
https://karyailham.com.my/index.php/feel
ISSN: 3083-8940



A Large Room Case Study of Facility Layout Problems Influences Energy Efficiency and Thermal Comfort

Noorhadila Mohd Bakeri[1], Mohd Faizal Omar[1,2,*], Mohd Nasrun Mohd Nawi[3]

[1] School of Quantitative Sciences, College of Arts and Sciences, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia
[2] Centre for Testing, Measurement and Appraisal (CeTMA), Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia
[3] School of Technology Management and Logistic, College of Business, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia

ARTICLE INFO

Article history:
Received 20 January 2025
Received in revised form 12 February 2025
Accepted 2 March 2025
Available online 21 March 2025

Keywords:
Facility layout problems; energy efficiency; thermal comfort

ABSTRACT

The FLP, or Facility Layout Problem, is a well-known and extensively examined issue that has received significant attention across multiple disciplines, including industry and manufacturing. One of the recent studies examines the issue of FLP in a large room. The study of the issue concerning large rooms, such as libraries, involves an analysis of how the arrangement of facilities and temperature settings significantly impact the thermal comfort of individuals and, consequently, the energy usage inside such large rooms. The arrangement of facilities typically impacts the air distribution within a large room. Inappropriate facility layout design may result in indoor temperature imbalances, wherein certain areas experience too much cold or heat. Thus, there exists an irregular distribution of users due to the varying thermal comfort of each individual. Previous researchers have discussed this issue. However, after a detailed examination of previous study, a few drawbacks have been identified in the process of building mathematical models. These drawbacks include issues such as poorly organised mathematical modelling, the presence of ambiguous or disorganised data collection and analysis techniques, as well as the absence or ambiguity of variables and constraints. Concerning FLP in large rooms and other energy-efficiency issues. Therefore, this study proposes a structured mathematical approach aimed at building a more efficient, inclusive, and reliable model. This study uses a university library in Malaysia as a case study. The list of the sub-competency of the modelling process is used as guidelines for building mathematical models in this work. The entire procedure for developing a mathematical model is laid out, and suggestions for the future are made. This work is seen as an important step towards conducting more FLP investigations in large rooms for the greater good in the future, which was part of the PhD research conducted at UUM.

1. Introduction

The arrangement of facilities in a plant area, often known as a facility layout problem, has a substantial impact on production expenses, system operation, lead times, and efficiency [1]. After important contributions from various research papers categorising facility layout issues as single-

* *Corresponding author.*
E-mail address: mohdnasrun@gmail.com

https://doi.org/10.37934/feel.2.1.6374

floor or multi-floor layout problems [2,3], facility layout problems (FLP) have acquired relevance. FLP has garnered significant interest among researchers due to its potential to enhance and optimise system efficiency across multiple domains within the research area. Many review studies have been undertaken by researchers to learn about the present state of FLP work, which include the review performed by Hosseini-Nasab *et al.,* Pérez-Gosende *et al.,* Monga *et al.,* and Anjos *et al.,* [4-7]. In order to gain a concise understanding of FLP investigations, the following subsections provide general definitions, classifications, and applications of FLP.

1.1 Figure Style and Format

FLP might be defined in several ways depending on the nature of the study at hand. In a nutshell, FLP is the process of arranging plant-site facilities to determine the optimal configuration given a set of constraints, such as the facilities' shapes, sizes, orientations, and origins/destinations [4,8-10]. Since the 1960s, many in-depth studies have been done, as written by Meller and Gau [3], which showed how the production system is physically set up. This has led to a lot of work and shows that FLP is very useful for making a wide range of different parts in variable production systems.

Hassan *et al.,* [11] showed that the structure of the production components has a big effect on how much these systems cost and how well they work. Laporte and Mercure [12] used FLP to balance the runners of hydraulic turbines. Brusco and Stahl [13] used FLP to initialise algorithms in numerical analysis. After many years of research, FLP is still being studied to find out how it can be used to solve layout problems in more serious ways in many fields and areas of life.

1.2 Classification of Facility Layout Problem

Facility layout problem (FLP) is a branch of facility planning research shown in Figure 1 below.

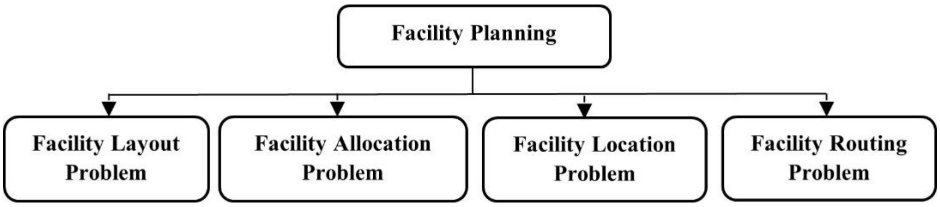


Fig. 1. The branches of facility planning [4]

Every division within the discipline of facility planning research serves a distinct goal and employs a particular technique. Nevertheless, this study exclusively concentrates on the examination of FLP. Therefore, since FLP was first discovered in the past few decades, the popularity of FLP studies has grown and caused researchers to take the initiative to conduct review studies, periodically. Hence, it is evident that the advancement of FLP can be observed through the evolution of FLP classification, which demonstrates the minimal difference in accordance with the development of FLP and current trends.

Hosseini-Nasab *et al.,* [4] conducted a comprehensive survey on the issue of FLP within the manufacturing and industrial sectors. Their study encompassed articles published between 1987 and 2016, resulting in the inclusion of 186 relevant publications covering a period of 30 years. In a recent publication, Pérez-Gosende *et al.,* [5] provided a comprehensive analysis of the categorisation of FLP within the context of operations management. A total of 232 publications, covering 10 years from 2011 to 2019, were chosen based on the assessment provided in their study. By considering their findings, the classification of FLP is depicted in the following Figure 2.

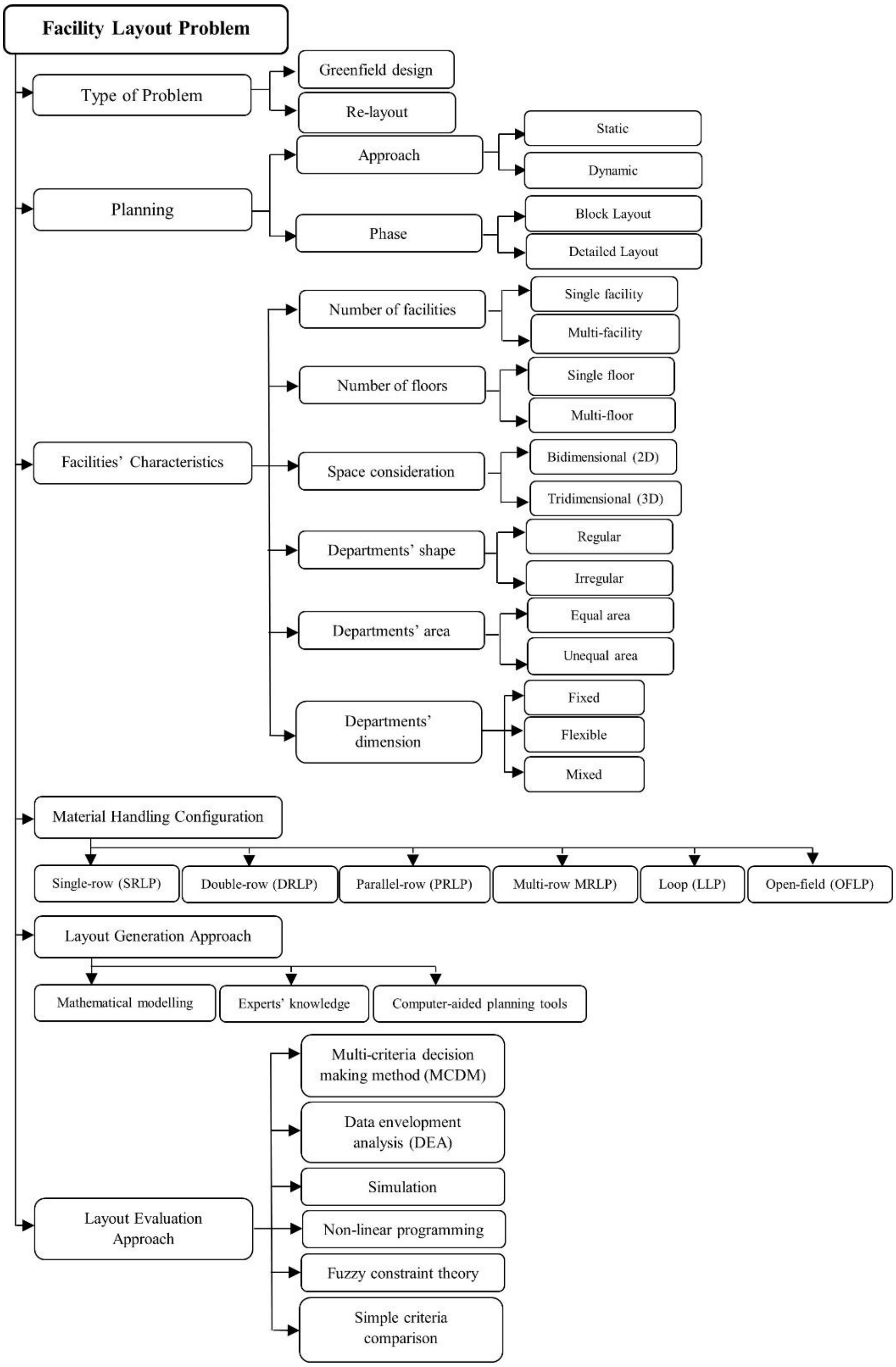


Fig. 2. Classification of FLP [4,5]

Figure 2 illustrates the inclusion of different classification criteria within the context of the FLP study. These criteria encompass problem type, planning approach and planning phase, facility characteristics, material handling configuration, layout generation approach and layout evaluation approach. Each criterion possesses its own distinct definition and includes additional sub-criteria that will be employed depending on the suitability of the case study problem. The FLP classification (Figure 2) acts as a basic structure for developing the facility layout design. Nevertheless, the evolution of FLP classification can be further enhanced and refined in accordance with the progression of time and the newest technological advancements. It should be noted that Figure 2 is derived from a comprehensive assessment conducted by Hosseini-Nasab *et al.,* [4] and Pérez-Gosende *et al.,* [5] which focuses on the manufacturing and industry sectors. The suitability of utilising the FLP classification may be limited in some situations.

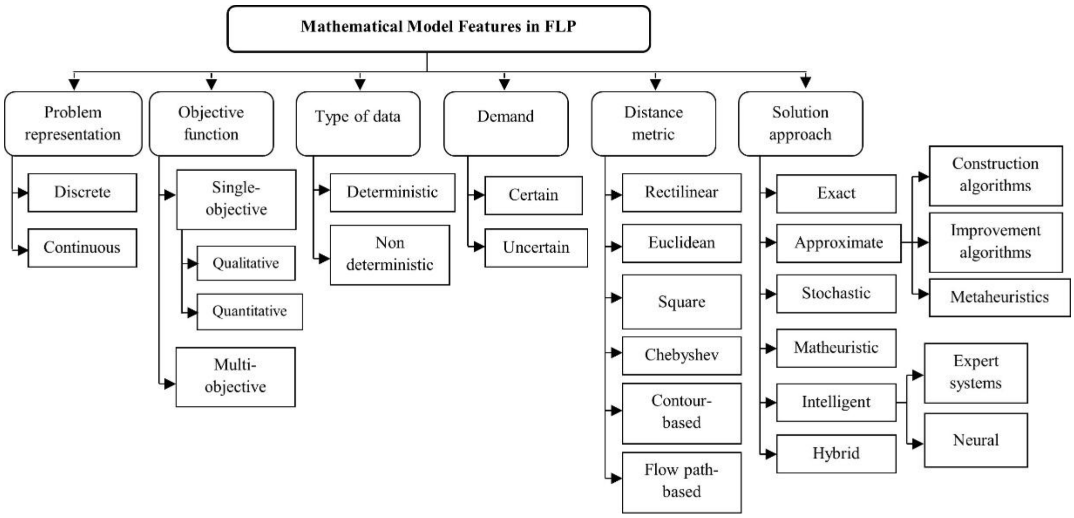


Fig. 3. Mathematical model features in FLP [5]

Moreover, Figure 3 highlights the features of mathematical models in the field of FLP. These basic features may be used as guidelines for researchers to identify and construct models that are both effective and efficient. The solution approach isn't restricted to the options mentioned above; it can encompass a wide range of possibilities.

1.3 Application in FLP and Recent Trend

The development of FLP began with the publication of the vital report by Koopmans and Beckmann in 1957. Koopman and Beckmann [14] initially introduced the FLP as a basic industrial challenge, employing the Quadratic Assignment Problem (QAP) model for its description. They say that its main objective is to organise facilities so as to minimise the cost of material transit. Later, FLP evolved with multiple meanings in diverse methods, perspectives, and circumstances. FLP is addressed in a wide variety of applications, including those used in manufacturing [15-17], healthcare facilities [18-20], construction sites [21,22], storage/warehouses [23-25], buildings [26] and other workplaces such as factories.

The use of FLP in manufacturing is the most well-known and has been the subject of extensive discussion and study. This is due to the fact that manufacturing is a highly essential sector of any country's economy. The layout of the facility is one of the most important factors in ensuring a well-functioning system in this field. For example, Guan *et al.,* [15] came up with the hybrid evolution algorithm (HEA) by integrating the exhaustive pairwise swap and variation processes to reduce the overall expense of the material handling and rearranging process. Durmaz and Şahin [17] apply the mixed integer programming (MIP) model to reduce transportation costs by optimising the multi-product double-row facility layout problem (DRFLP) with various processing paths. Zhang *et al.,* [16] offer an energy-efficient facility layout (EFL) model optimised using the particle swarm optimization (PSO) approach with two goals in mind: to decrease total load transport length and create optimal energy consumption (EC).

However, other areas also demonstrate their significance in FLP. According to past studies, the optimisation of layout arrangement has several purposes, including reducing a) operating costs, b) material handling costs, c) transportation costs and times, d) travel distance, and e) the amount of communication needed between facilities, all while increasing output. In addition, there are niche or under-researched uses for FLP that have yet to be fully explored. New or rarely utilised FLP studies include cabin ships [27-29] and large room layouts [26]. Nevertheless, the scope of this study was limited to examining the effects of FLP exclusively in large rooms. The following section will provide an in-depth overview of the study's details. Section 2 goes further into a thorough discussion of the existing literature on FLP in large rooms. Section 3 analyses the gaps in the literature. Section 4 addresses the solution approach for FLP in large rooms.

2. Literature Review

FLP studies are typically conducted in indoor environments, such as manufacturing facilities, factories, hospitals, and other similar settings. The main concern during the implementation of the FLP in buildings is the optimisation of energy efficiency. The topic of energy efficiency concerns in the FLP study has been a subject of longstanding interest, however, the findings are unfortunately less than promising. This is due to the fact that energy efficiency is a complex matter that takes into account various other factors, particularly when it is incorporated into the FLP study.

Some examples of studies on the application of FLP in the context of energy efficiency include: Cullinane and Tompkins [30] were pioneers in noticing the significance of energy efficiency as a crucial factor in achieving layouts of high quality. Their research suggests that energy is a precious resource that must be included from the outset of design. Some energy-intensive businesses, for instance, have rearranged their facility's layout so that the heat generated during manufacturing is used to warm the offices. Yang and Deuse [31] agreed that energy efficiency should be considered at the outset of design. They suggested a hybrid strategy for solving a layout problem by combining the analytic hierarchy process (AHP) and preference ranking organization methods for enrichment evaluations (PROMETHEE), with the goal of optimising energy efficiency. Concerned with this issue, FLP in large rooms is a recent study on this topic that will be discussed in this study. Several additional constraints were also considered as significant factors.

2.1 FLP in Large Room

The term "large" is commonly used to describe objects or quantities that are significant in size or volume, exceeding the typical or average dimensions or amounts [32]. So, FLP in a large room refers to the layout of facilities in a large space that has certain dimensions and constraints. The topic of FLP in large rooms was examined by Qiao *et al.,* in their 2019 study. The researchers' analysis focuses on two primary concerns, specifically thermal comfort and energy savings. In order to address this matter, efforts were made to enhance the layout design and optimise the air conditioning control system (ACC).

Based on their research findings, it has been identified that the arrangement of the facility will have an impact on several factors, including air distribution and room temperature. This scenario leads to an imbalanced distribution of people within the room, as a result of varying room temperatures and differences in thermal comfort among the people in the room. From a logical standpoint, people seeking places will typically choose the most comfortable option that aligns with their preferred thermal conditions. Consequently, this condition can have an indirect impact on energy usage and electricity expenses in the building. Hence, they propose to optimise the set point of the ACC system and the facility layout design utilising the PSO method. Their findings of the study indicate a notable 27% increase in thermal satisfaction rate and a corresponding 24.3% reduction in daily power costs when compared to the manual control approach.

The study conducted by Qiao *et al.,* [26] delivered significant findings in the field of FLP in large rooms. There are multiple reasons for this occurrence: 1) managing user comfort in large rooms offers greater challenges compared to small rooms, 2) the impact of energy savings is mostly important due to its utilisation in large room, and 3) a well-designed facility layout plays a crucial role in enhancing the organisation's services and attracting future users.

Motivated by this significant discovery, the present work aims to identify strategies for enhancing some areas that exhibit potential for improvement. In this study, the large room of the library will serve as the case study's location. The main focus is to improve the effectiveness of the facility layout and determine the optimal set point temperature for the air conditioning system. Both objectives aim to increase user comfort while simultaneously achieving energy savings and reducing electricity expenses. In the study of Qiao *et al.,* [26], several drawbacks were identified. Then, the next section will list and describe the limitations present in this study.

3. Gap in Literature

As stated previously, a number of gaps have been identified, including:

i. Not well-structured mathematical modelling

A previous study by Qiao *et al.,* [26] suggests three different mathematical models that are seen as a bit messy and less structured. Unstructured mathematical models make it hard to understand the flow of the optimisation process as well as difficult to solve problems.

ii. Uncertain or disorganised data collection and analysis procedure

Qiao *et al.,* [26] likewise demonstrated a relatively disorganised and unreliable data-gathering framework. This is due to the fact that their research builds upon the work of Qiao, Zhang, Wu, and Li [33]. So, it's quite possible that a lot of unstable data will be collected.

iii. Missing or unclear variables/constraints related to FLP in large rooms

The present investigation by Qiao *et al.,* [26] builds upon the previous study conducted by Qiao *et al.,* [33]. Consequently, it is possible that certain variables or constraints may be absent or ambiguous during the construction of the FLP model. The significance of this process lies in its potential impact on the precision of the study's ultimate findings.

4. Formulation of The Problem for FLP in a Large Room using a Case Study in a Library of a Higher Education University

4.1 Case Study Description

The selected case study for this research comprises a large room at a university library located in a higher education institution in Malaysia. In this study, a new library building with three floors and a closed room is used. This building is thought to meet the criteria for large rooms with an area over $1980m^2$. The building is equipped with a variety of facilities including bookshelves, a collection of books, computer systems, specific office areas, electronic equipment, as well as tables and chairs, and others. Because it is a library, the facilities are laid out to meet the needs of the users, and the temperature is kept within a comfortable range. In order to make building management easier, like putting books in the right place and keeping track of resources in the library, the layout of facilities is set up based on building management goals. However, there are no guidelines that are specific to these library buildings [34]. Hence, this study will provide extra benefits in the management of facilities within the library.

4.2 Problem Formulation

As described by Qiao *et al.,* [26], large rooms can accommodate a number of people at a time. Typically, each user will occupy an area that is conducive to their thermal comfort. The environment should be neither too chilly nor too hot. The environment's temperature is influenced directly by a set point temperature and indirectly by the facility's layout. The layout of a facility affects how air moves around in large rooms, which affects the temperature. This factor causes the distribution of people in a large room to become scattered. It is crucial to resolve this issue, particularly in order to optimally control energy consumption in large rooms and user thermal comfort.

The investigation will make use of the general mathematical model developed by Qiao *et al.,* [26]. In keeping with the existing framework, modifications will be implemented and certain variables will be eliminated as considered necessary for the case study. A comprehensive investigation will be performed in line with established procedures. The general mathematical model of Qiao *et al.,* [26] is represented as follows.

Mathematical model: Maximising the total TSR by figuring out t_{input_k} at different outside temperatures and with different facility layouts.

Objective function:
Maximize

$$(\beta_1 + \beta_2 + \beta_3) / \left(\sum_{i=1}^{n}[(1 - x_i) \times \alpha_{1i}] + \sum_{i=1}^{n}\left[y_i \times \frac{1}{s}(\sum_{i=1}^{n} x_i \times z_i - b)\right] + \sum_{i=1}^{n} \alpha_{2j} \right) \quad (1)$$

Subject to:

$$\sum_{k=L}^{H}\left\{\omega_k \times \sum_{i=1}^{n}\left[(1 - x_i) \times \alpha_{1i} \times g\left(f_i\left(t_{input\_k}, k\right)\right)\right]\right\} = \beta_1 \quad (2)$$

$$\sum_{k=L}^{H}\left\{\omega_k \times \sum_{i=1}^{n}\left[y_i \times \frac{1}{s}(\sum_{i=1}^{n} x_i \times z_i - b) \times g\left(f_i\left(t_{input\_k}, k\right)\right)\right]\right\} = \beta_2 \quad (3)$$

$$\sum_{k=L}^{H}\left\{\omega_k \times \sum_{i=1}^{m}\left[\alpha_{2j} \times g\left(F_i\left(t_{input\_k}, k\right)\right)\right]\right\} = \beta_3 \quad (4)$$

$$x_i \in \{0,1\}, i \in {N^+}_n \quad (5)$$

$$y_i \in \{0,1\}, i \in {N^+}_n \quad (6)$$

$$x_i \geq y_i, i \in {N^+}_n \quad (7)$$

$$\sum_{i=1}^{n} y_i \leq 1 \quad (8)$$

$$\sum_{i=1}^{n} z_i \times x_i \geq b \quad (9)$$

$$\sum_{i=1}^{n}(z_i \times x_i) - \sum_{i=1}^{n}(z_i \times y_i) \leq b \quad (10)$$

$$210 \leq \lambda \leq 250, \lambda \text{ is an integer} \quad (11)$$

$$t_{input\_k} = \lambda/10 \quad (12)$$

Meanwhile, f_i, F_i and $g(t)$ can be interpreted as follows,

$$f_i\left(t_{input}, t_{out}\right) = a_{oi} + a_{1i} \times t_{input} + a_{2i} \times t_{out}, i \in N_n^+ \quad (13)$$

$$F_i\left(t_{input}, t_{out}\right) = {a'}_{0i} + {a'}_{1i} \times t_{input} + {a'}_{2i} \times t_{out}, i \in N_m^+ \quad (14)$$

$$g(t) = -a_1 \times (t - t^*)^2 + a_2 \quad (15)$$

The above model uses the binary values 0 and 1 in the variables x_i and y_i to indicate the location of the room's facilities. x_i and y_i are used as response variables to figure out the best way to set up the facility, while t_{input_k} and t_{out} are used to manipulate the real temperature inside the room and the temperature outside the room. Eq. (1) is the objective function for the FLP in a large room. Eq. (2) to (12) are constraints that must be fulfilled.

The function $g(t)$, as defined in Eq. (15), is utilised for the purpose of predicting the TSR value, presented as a percentage. a_1, a_2, and t^* are the parameters to be fitted. t^* is used as a reference point where the TSR value reaches its peak when $t = t^*$ and falls or rises when $t < t^*$ or $t > t^*$. In order to obtain a more accurate TSR value, it is essential to fit the function $g(t)$ in Eq. (15) with a maximum possible value of R^2, which is in close proximity to 1. It should be noted that the case study can be modified by adding or removing objective functions and constraints. Case study requirements must be discovered, analysed, and confirmed by experts or decision-makers.

In order to have an in-depth list of constraints. The method of searching and identification is conducted by a comprehensive assessment of previous studies. A study is considered that relates to or is at least indirectly connected to, the layout of facilities within any particular room or building. The study of the arrangement of facilities in a large room is one that receives little attention from researchers. Hence, there is a lack of references regarding to specific studies on the arrangement of facilities inside large rooms. The closest study is then identified, filtered, reviewed, and confirmed by the decision-maker. The following phases are utilised in the development of mathematical modelling [35]:

i. Phase 1: Understand a situation or problem and simplify the situation

During this phase, it is very important to understand the real issue of FLP in large rooms, make assumptions and simplify the situation, find variables, make connections between variables, find information, and figure out what information is important and what information is not.

ii. Phase 2: Formulate a mathematical model

In this phase, a mathematical model for the FLP in a large room is constructed, with a specific focus on the research objectives and relevant constraints that have been selected. In order to successfully go to the next step, it is important to possess a solid understanding of the model in mind. Models should be simplified to reduce the number and complexity of variables.

iii. Phase 3: Solve or analyse model

Meanwhile, when solving and analysing the model, there are many paths and parts that need to be thought over and gone through in order to get a model that works effectively, makes meanings, and fits the real situation in large room problems. A high-quality model will produce robust, stable, and reliable outcomes. In this study, the metaheuristic method, which is part of the Swarm Intelligence (SI) group, will be used. Since FLP in a large room is an NP-hard problem, the metaheuristic approach is generally considered to be the most appropriate and effective one. SI is known to be the most powerful method because it is a well-known method in FLP studies.

iv. Phase 4: Interpret solution and draw conclusion

The outcomes derived from the previous phases are further analysed and conclusions are made. The optimal layout design identified in this study requires interpretation and evaluation in order to fully understand the broader context of FLP studies, particularly for large room studies.

Nomenclature

b	The total size required for placing all facilities	t_{input}	The set-point temperature of an ACC system
$F_i(t_{input}, t_{out})$	A predictor of t_{2j}	t_{out}	The outside temperature
$f_i(t_{input}, t_{out})$	A predictor of t_{1i}	t_{input_k}	The set-point temperature of an ACC system with $t_{out} = k$
$g(t)$	A predictor of γ_t	a_{oi}, a_{1i}, a_{2i}	Parameters to be determined for $f_i(t_{input}, t_{out})$
H	The highest outside temperature ($H^o C$)	$a'_{0i}, a'_{1i}, a'_{2i}$	Parameters to be determined for $F_i(t_{input}, t_{out})$
L	The lowest outside temperature ($L^o C$)	s	The size that is required for a person to stay in an area
n	The number of undetermined areas	α_{1i}	The number of persons that the *i*-th undetermined area can accommodate
m	The number of determined areas	α_{2j}	The number of persons that the *j*-th determined area can accommodate
R^2	The coefficient of determination for the statistical value	β_1	The number of persons who feel comfortable when they are staying in the undetermined areas with t_{out}
x_i	Binary variable. If $x_i = 1, i \in N_n^+$, it means that the *i*-th area is used for placing facilities; otherwise, it is occupied by persons	β_2	The number of persons who feel comfortable when they are staying in the undetermined area that is also shared for facilities with $t_{out} = k$
y_i	Binary variable. If $y_i = 1, i \in N_n^+$, the *i*-th area is partially for facilities; otherwise, it is either occupied entirely by facilities or persons	β_3	The number of persons who feel comfortable in the determined areas with $t_{out} = k$
z_i	The size of the *i*-th undetermined area	ω_k	The proportion of the total time with the outside temperature being $k^o C$ to the total time that an ACC system runs during a year
t_{1i}	The temperature of the *i*-th undetermined area	γ_t	The thermal satisfaction rate when the temperature is $t^o C$
t_{2j}	The temperature of the *j*-th determined area		

v. Phase 5: Validate conclusion

At this point, critical evaluation and reflection are necessary. If there are aspects of the model that aren't appropriate to the situation, the process of modelling the layout of facilities in a large room can be repeated using alternative techniques. To ensure that this model is effective, some queries based on objective research can be formulated to assess the model's capacity to answer them.

vi. Phase 6: Report out

Lastly, models that have been shown to work effectively in large rooms with optimal layout design should be reported and discussed.

To better understand the entire process of mathematical modelling, the Figure 4 provided below is presented.

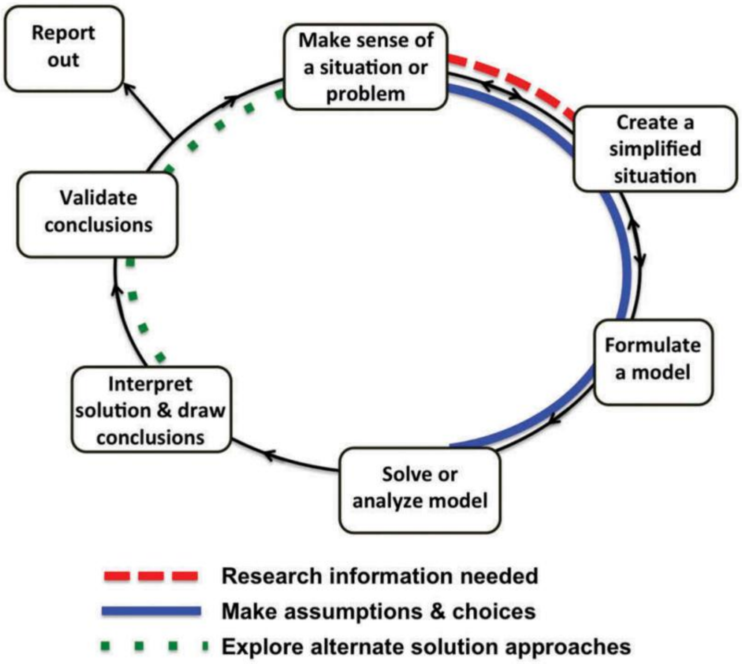


Fig. 4. A representation of the mathematical modelling process [36]

Hence, in order to ensure the success and completion of all gaps. It is vital to use attention to detail and caution when undertaking any mathematical modelling development procedures. Finally, the main goal of the study was successfully achieved.

5. Conclusion and Future Works

This study provides a concise overview of the background history of FLP studies done over the past few decades. The literature on FLP contains its definition, classification, and application through a range of studies conducted from earlier until more recent times. The most recent study, FLP in a large room, looks at several important factors that researchers often talk about but don't pay enough attention to, namely the energy efficiency of FLP studies. The study conducted by Qiao *et al.,* [26] focused on investigating the issue of FLP in large rooms with the goal of improving both user thermal comfort and energy efficiency. Then, efforts are made to enhance the efficiency of the facility's layout design and regulate the set point of the ACC system.

However, by careful examination of the FLP study conducted by Qiao *et al.,* [26], a number of drawbacks were identified. These include poorly structured mathematical modelling, disorganised data collection and analysis procedures, and missing or ambiguous variables and constraints related to FLP in a large room. Therefore, this study proposes to improve previous work by presenting a more systematic and organised process for constructing FLP models. The method is thoroughly described and clarified, covering all the relevant details.

Future research plans aim for the full implementation of the FLP study in a large room, the thorough investigation of library case studies, and the development of mathematical modelling. This mathematical model is considered to be applicable to any large room with nearly the same environmental conditions and constraints. For future benefits, it is strongly recommended that FLP in large rooms be studied in greater depth.

Acknowledgement
This research was supported by Ministry of Higher Education (MoHE) of Malaysia through Fundamental Research Grant Scheme (FRGS/1/2019/TK07/UUM/02/1). Our gratitude also goes to Research and Innovation Centre and The Library of Universiti Utara Malaysia for giving us an opportunity to conduct a case study for this project. We also like to express outmost gratitude to all parties involved directly or indirectly in the completion of the study.

References

[1] Drira, Amine, Henri Pierreval, and Sonia Hajri-Gabouj. "Facility layout problems: A survey." *Annual reviews in control* 31, no. 2 (2007): 255-267. https://doi.org/10.1016/j.arcontrol.2007.04.001
[2] Kusiak, Andrew, and Sunderesh S. Heragu. "The facility layout problem." *European Journal of operational research* 29, no. 3 (1987): 229-251. https://doi.org/10.1016/0377-2217(87)90238-4
[3] Meller, Russell D., and Kai-Yin Gau. "The facility layout problem: recent and emerging trends and perspectives." *Journal of manufacturing systems* 15, no. 5 (1996): 351-366. https://doi.org/10.1016/0278-6125(96)84198-7
[4] Hosseini-Nasab, Hasan, Sepideh Fereidouni, Seyyed Mohammad Taghi Fatemi Ghomi, and Mohammad Bagher Fakhrzad. "Classification of facility layout problems: a review study." *The International Journal of Advanced Manufacturing Technology* 94 (2018): 957-977. https://doi.org/10.1007/s00170-017-0895-8
[5] Pérez-Gosende, Pablo, Josefa Mula, and Manuel Díaz-Madroñero. "Facility layout planning. An extended literature review." *International Journal of Production Research* 59, no. 12 (2021): 3777-3816. https://doi.org/10.1080/00207543.2021.1897176
[6] Monga, Rohit, and Varinder Khurana. "Facility layout planning: a review." *Int. J. Innov. Res. Sci. Eng. Technol* 4, no. 03 (2015): 976-980. https://doi.org/10.15680/IJIRSET.2015.0403027
[7] Anjos, Miguel F., and Manuel VC Vieira. "Mathematical optimization approaches for facility layout problems: The state-of-the-art and future research directions." *European Journal of Operational Research* 261, no. 1 (2017): 1-16. https://doi.org/10.1016/j.ejor.2017.01.049
[8] Suhardi, Bambang, Lulu Elvira, and Rahmaniyah Dwi Astuti. "Facility Layout Redesign Using Systematic Layout Planning Method in Pt. Pilar Kekar Plasindo." *Journal of Technology and Operations Management (JTOM)* 16, no. 1 (2021): 57-68. https://doi.org/10.32890/jtom2021.16.1.5
[9] Ripon, Kazi Shah Nawaz, Kyrre Glette, Kashif Nizam Khan, Mats Hovin, and Jim Torresen. "Adaptive variable neighborhood search for solving multi-objective facility layout problems with unequal area facilities." *Swarm and Evolutionary Computation* 8 (2013): 1-12. https://doi.org/10.1016/j.swevo.2012.07.003
[10] García-Hernández, Laura, Henri Pierreval, Lorenzo Salas-Morera, and Antonio Arauzo-Azofra. "Handling qualitative aspects in unequal area facility layout problem: an interactive genetic algorithm." *Applied Soft Computing* 13, no. 4 (2013): 1718-1727. https://doi.org/10.1016/j.asoc.2013.01.003
[11] Hassan, Mohsen MD. "Machine layout problem in modern manufacturing facilities." *The International Journal of Production Research* 32, no. 11 (1994): 2559-2584. https://doi.org/10.1080/00207549408957084
[12] Laporte, Gilbert, and Hélène Mercure. "Balancing hydraulic turbine runners: A quadratic assignment problem." *European Journal of Operational Research* 35, no. 3 (1988): 378-381. https://doi.org/10.1016/0377-2217(88)90227-5
[13] Brusco, Michael J., and Stephanie Stahl. "Using Quadratic Assignment Methods to Generate Initial Permutations for Least-Squares Unidimensional Scaling of Symmetric Proximity Matrices." *Journal of Classification* 17, no. 2 (2000). https://doi.org/10.1007/s003570000019
[14] Koopmans, Tjalling C., and Martin Beckmann. "Assignment problems and the location of economic activities." *Econometrica: journal of the Econometric Society* (1957): 53-76. https://doi.org/10.2307/1907742
[15] Guan, Chao, Zeqiang Zhang, Lixia Zhu, and Silu Liu. "Mathematical formulation and a hybrid evolution algorithm for solving an extended row facility layout problem of a dynamic manufacturing system." *Robotics and Computer-Integrated Manufacturing* 78 (2022): 102379. https://doi.org/10.1016/j.rcim.2022.102379

[16] Zhang, Zhongwei, Lihui Wu, Zhaoyun Wu, Wenqiang Zhang, Shun Jia, and Tao Peng. "Energy-Saving Oriented Manufacturing Workshop Facility Layout: A Solution Approach Using Multi-Objective Particle Swarm Optimization." *Sustainability* 14, no. 5 (2022): 2788. https://doi.org/10.3390/su14052788

[17] Durmaz, Esra Duygu, and R. A. M. A. Z. A. N. Şahin. "Mathematical model proposals for multi-product double row facility layout problem with identical machines." *Journal of the Faculty of Engineering and Architecture of Gazi University* 37, no. 4 (2022): 1855-1867. https://doi.org/10.17341/gazimmfd.958700

[18] Teran-Somohano, Alejandro, and Alice E. Smith. "A sequential space syntax approach for healthcare facility layout design." *Computers & Industrial Engineering* 177 (2023): 109038. https://doi.org/10.1016/j.cie.2023.109038

[19] Cubukcuoglu, Cemre, Pirouz Nourian, M. Fatih Tasgetiren, I. Sevil Sariyildiz, and Shervin Azadi. "Hospital layout design renovation as a Quadratic Assignment Problem with geodesic distances." *Journal of Building Engineering* 44 (2021): 102952. https://doi.org/10.1016/j.jobe.2021.102952

[20] Halawa, Farouq, Sreenath Chalil Madathil, and Mohammad T. Khasawneh. "Multi-objective unequal area pod-structured healthcare facility layout problem with daylight requirements." *Computers & Industrial Engineering* 162 (2021): 107722. https://doi.org/10.1016/j.cie.2021.107722

[21] Li, Guokai, Jingkuang Liu, and Andrea Giordano. "Robust optimization of construction waste disposal facility location considering uncertain factors." *Journal of Cleaner Production* 353 (2022): 131455. https://doi.org/10.1016/j.jclepro.2022.131455

[22] O'Neill, Sam, Paul Wrigley, and Ovidiu Bagdasar. "A mixed-integer linear programming formulation for the modular layout of three-dimensional connected systems." *Mathematics and Computers in Simulation* 201 (2022): 739-754. https://doi.org/10.1016/j.matcom.2021.09.019

[23] Hu, Xiulian, and Yi-Fei Chuang. "E-commerce warehouse layout optimization: systematic layout planning using a genetic algorithm." *Electronic Commerce Research* 23, no. 1 (2023): 97-114. https://doi.org/10.1007/s10660-021-09521-9

[24] Shangguan, Yidan, and Ye Zhu. "A Method for Multi-Objective Facility Layout Problem of Land Port Logistics Hub Considering the Impact of Traffic Organization." In *CICTP 2022*, pp. 1171-1182. 2022. https://doi.org/10.1061/9780784484265.110

[25] Biçer, Bernis, Elif Sayılı, Müge Ağaçhan, Batuhan Dündar, Sabri Can Doğantay, Yigit Kazancoglu, and Melisa Ozbiltekin Pala. "Facility Layout Design for Dangerous Goods Containers in the Warehouse." In *The International Symposium for Production Research*, pp. 807-817. Cham: Springer International Publishing, 2022. https://doi.org/10.1007/978-3-031-24457-5_64

[26] Qiao, Yan, SiWei Zhang, NaiQi Wu, Xu Wang, ZhiWu Li, MengChu Zhou, and Ting Qu. "Data-driven approach to optimal control of ACC systems and layout design in large rooms with thermal comfort consideration by using PSO." *Journal of Cleaner Production* 236 (2019): 117578. https://doi.org/10.1016/j.jclepro.2019.07.053

[27] Su, Shaojuan, Yasai Zheng, Jinan Xu, and Tianlin Wang. "Cabin placement layout optimisation based on systematic layout planning and genetic algorithm." *Polish Maritime Research* 27, no. 1 (2020): 162-172. https://doi.org/10.2478/pomr-2020-0017

[28] Wang, Yun-long, Zhang-pan Wu, Guan Guan, and Chao-guang Jin. "Research on Intelligent Design Method of Ship Cabin Layout." *Marine Technology Society Journal* 54, no. 2 (2020): 79-92. https://doi.org/10.4031/MTSJ.54.2.8

[29] Li, Jinghua, Hui Guo, Shichao Zhang, Xiaoyuan Wu, and Liuling Shi. "Optimum design of ship cabin equipment layout based on SLP method and genetic algorithm." *Mathematical Problems in Engineering* 2019 (2019): 1-14. https://doi.org/10.1155/2019/9492583

[30] Cullinane, T. P., and J. A. Tompkins. "Facility layout in the'80s: The changing considerations." *Industrial Engineering* (1980): 34-42.

[31] Yang, L., and J. Deuse. "Multiple-attribute decision making for an energy efficient facility layout design." *Procedia CIRP* 3 (2012): 149-154. https://doi.org/10.1016/j.procir.2012.07.027

[32] Cambridge University Press & Assessment. "Large", April 2, 2025.

[33] Qiao, Yan, SiWei Zhang, NaiQi Wu, and ZhiWu Li. "Optimization on ACC Systems and Layout Design for Maximizing Thermal Comfort and Energy Saving in Large Rooms-A Case Study." In *2019 IEEE Congress on Evolutionary Computation (CEC)*, pp. 654-659. IEEE, 2019. https://doi.org/10.1109/CEC.2019.8790095

[34] Bakeri, Noorhadila Mohd. "Critical constraints of facility layout problem for Sultanah Bahiyah Library" (Masters thesis, Universiti Utara Malaysia, 2021).

[35] Maaß, Katja. "What are modelling competencies?." *ZDM* 38 (2006): 113-142. https://doi.org/10.1007/BF02655885

[36] Anhalt, Cynthia Oropesa, Ricardo Cortez, and Amy Been Bennett. "The emergence of mathematical modeling competencies: An investigation of prospective secondary mathematics teachers." *Mathematical Thinking and Learning* 20, no. 3 (2018): 202-221. https://doi.org/10.1080/10986065.2018.1474532