FRACTAL OFFICE LAYOUTS CONSIDERING ERGONOMICS

N. Fırat ÖZKAN[1*], Berna HAKTANIRLAR ULUTAŞ[2]

[1] Eskisehir Osmangazi University, Engineering and Architecture Faculty,
Meselik Campus, Department of Industrial Engineering, Eskisehir
ORCID No : http://orcid.org/0000-0003-4464-7052
[2] Eskisehir Osmangazi University, Engineering and Architecture Faculty,
Meselik Campus, Department of Industrial Engineering, Eskisehir
ORCID No : http://orcid.org/0000-0003-1886-9979

Keywords
Office ergonomics
Cell type office layout
Mixed integer programming
Fractal layout

Abstract
A number of studies in literature focus on seated workers and investigate physical workload, related back/neck pain, environmental ergonomics such as illumination, thermal comfort, cooperation, and work organization. Although, the positioning of furniture and related units may directly or indirectly influence the performance of workers, up-to best knowledge, the office layout problem is not studied in detail. Therefore, this study aims to illustrate how fractal layout concept can be adapted for cell type office layouts. The study is novel because, the constraints of a basic mathematical model that is originally defined for unequal area facility layout problem is redefined as to meet the ergonomic requirements and generate a layout. Proposed approach is used to solve the office layout problem in a university department. It is concluded that the layout obtained by considering the closeness ratings defined by office employees along with the redefined constraints outperforms the current layout.

ERGONOMİ GÖZ ÖNÜNDE BULUNDURULARAK FRAKTAL OFİS YERLEŞİMİ

Anahtar Kelimeler
Ofis ergonomisi
Hücre tipi ofis yerleşimi
Karma tamsayılı programlama
Fraktal yerleşim

Öz
Oturarak çalışanlar için literatürdeki çalışmalar, sırt/boyun ağrısı ile ilişkilendirilen fiziksel iş yükü, aydınlatma, sıcaklık konforu gibi çevresel faktörler ve iş organizasyonu ile ilgili konularla ilişkilendirilmektedir. Ofis yerleşim probleminde mobilyaların konumu doğrudan ya da dolaylı olarak çalışanların performansını etkileyebilmektedir fakat bilindiği kadarıyla bu konu yeterince ele alınmamıştır. Bu yüzden, bu çalışmada fraktal yerleşim konseptinin hücre tipi ofis yerleşimine nasıl uyarlanacağı temsil edilmiştir. Çalışma, temelde eşit olmayan alanlı tesis yerleşimi için geliştirilen matematiksel modelin, ergonomi gereksinimlerini de karşılayacak şekilde yeniden tanımladığı için özgündür. Önerilen yaklaşım, bir üniversitenin bölümlerinde bulunan ofis yerleşim problemi için uygulanmıştır. Ofis çalışanları tarafından tanımlanan yakınlık ilişkileri ve yeniden düzenlenen kısıtlar sonucu elde edilen yerleşimin mevcut yerleşimden daha iyi olduğu sonucuna ulaşılmıştır.

Araştırma Makalesi		Research Article	
Başvuru Tarihi	: 25.11.2019	Submission Date	: 25.11.2019
Kabul Tarihi	: 18.02.2020	Accepted Date	: 18.02.2020

1. Introduction

Facility layout problems can be defined as the placement of the machines/departments in the plant area. One of the best known layout types in practice is the process oriented functional layout, where machines of the same type are located in the same area. Cellular layout type, where machines are grouped in cells and each cell is responsible for the complete manufacturing of a part family. These types of manufacturing layouts have their advantages and disadvantages. Venkatadri, Rardin and Montreuil (1997) and Montreuil, Venkatadri and Rardin, (1999), propose a fractal layout for job shop environments in order to gain the flow time advantages of cellular manufacturing and the flexibility of a functional layout. Machines are grouped in various fractals, which are (more or less) identical cells able to produce all products in a fractal layout and enables the cell layout to deal with changes in demand and product mix. Main drawback of the layout is the requirement of workers and machines specialization. Details of the facility layout literature are available in studies such as Drira, Pierreval and Hajri-Gabouj (2007) and Anjos and Vieira (2017) to name a few.

* Sorumlu yazar; e-posta : ozkanfirat@gmail.com

Office layout is basically defined as the systematic arrangement of office equipment, machines and furniture and providing adequate space to office personnel for regular performance of work with efficiency (Durmusoglu and Kulak, 2008). Faulty or improper arrangement of furniture, equipment and space for employees leads to waste of time and energy and increase in the cost of office operations. Office layout may also be classified into two categories. In a process layout, equipment and employees are arranged according to the sequence of operations (i.e, the filing section may be located next to the dispatch section and so on). In group layout, employees are placed in a separate partition where similar activities are carried on and office machines are fitted with another section (i.e., all computers are fitted in separate room).

In an office layout problem, the departments of a facility layout problem correspond to the units such as tables, office chair, visitor seats, computers, etc. and the aim is to locate the related employees or units in closer locations based on their affinity. The ergonomic requirements concerning the design of computerized offices may involve the office equipment (i.e. monitor/screen, keyboard, desk/work surface, and seat), the environmental conditions (i.e. work space, lighting, noise, thermal environment and static electricity), the software (i.e. usability-related issues), and the work organization (i.e. macro-ergonomics issues).

Based on the accessible literature, it can be stated that physical office layouts are not studied in detail. Therefore, a mathematical model is revised to determine optimum locations of components used in an office environment by considering ergonomic aspects. Main aim of the study is to adapt fractal design concept for office layouts.

Second section provides general ergonomics requirements that can be considered in an office environment. The results of the fractal office layout application for a university department are discussed in the third section. Last section concludes the study.

2. Method

The layout of office workstations meeting the ergonomics principles is a complex task. Due to the interdependence between the workplace, components, the working persons, their task requirements, the physical environment, the building characteristics, and work performance should be considered and an important number of requirements, some of which may be contradictory, should be met.

2.1.Research design

Environmental requirements for an office are usually summarized as; no annoying reflections or glare on the computer screen and in the general work area, lighting should be uniform throughout the user's visual field, and no annoying hot or cold draughts in the workplace. Likewise, the layout of the workplaces should facilitate the work flow (both of the personnel and the visitors) and the access to the workstation should be unobstructed and safe. Steward (1985) states that improving the design of equipment, workplaces, and working environments in offices are no longer seen as a desirable objective and more emphasis is now being placed on a systems approach. The early studies on office employees have stated that "poor" ergonomics in office work settings, including physical design, work organization design, and psychosocial aspects of work, have been associated with physical discomfort and symptoms. (Bergqvist, Wolgast, Nilsson & Voss, 1995; Hales, Sauter, Peterson, Fine, Putz- Anderson, Schleifer, Ochs and Bernard, 1994; Hünting, Laubli and Grandjean, 1981; Sauter, Schleifer and Knutson, 1991). Figure 1 summarizes the general factors that may affect the job satisfaction of office employees. In a more recent study, Lee, Wargocki, Chan, Chen and Tham (2020), investigate the effects of indoor environmental quality on workers through measurements and statistical analyzes for green refurbished offices which are located in Green Mark certified buildings.

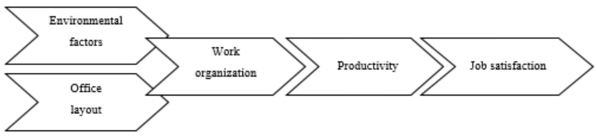


Figure 1. General Factors Effecting Office Employee Job Satisfaction

Lighting and vision in office working environments are studied because workers may feel fatigue and discomfort trying to read poor screens with reflections and glare. Küller, Ballal, Laike, Mikellides and Tonello (2006), investigate whether the indoor lighting and colour would have impact on the mood of people working indoors.

Acoustics may impact office worker's concentration, distraction, and stress. Therefore, Banburry and Berry (2005) study the office noise and employee concentration in open offices and Kaarlela-Tuomaala, Helenius, Keskinen and Hongisto (2009), investigate the acoustic environment, and its effects in private office rooms and in open-plan offices to name a few. Heating and ventilation may also affect workers. Lan, Lian, and Pan (2010), evaluate the effects of air temperature on office workers' well-being, workload, and productivity. Recently, Shahzad, Brennan, Theodossopoulos, Hughes and Calautit (2017), study the impact of individual thermal control and compare Norwegian cellular and British open plan offices.

Seating, desking, and possible health problems are the most popular topics in office ergonomics studies. Main aim is to reduce fatigue and discomfort from awkward postures. Joines and Sommerich (2001) conduct the research to determine if anthropometric and office workstation measurements could be accurately collected individually by the employees and partnered-assessment. Szetoa, Straker and O'Sullivan (2005), examine the muscle activity in the neck and shoulder regions in symptomatic and symptomatic office workers when they performed standardized keyboard tasks. Delisle, Larivière, Plamondon and Imbeau (2006), aim to determine whether resting the forearms on the work surface, as compared to chair armrests, reduces muscular activation and to compare the sensitivity of different electromyography (EMG) summary parameters. Robertson, Huang, O'Neill and Schleifer (2008), focus on flexible workspace design and ergonomics training to examine the effects on psychosocial work environment, musculoskeletal health, and work effectiveness in a computer-based office setting. Toomingas and Gavhed (2008), study the workstation layout and work postures among computer operators. Coluci, Alexandre and Rosecrance (2009), translate and adapt a Job Factors Questionnaire and assessed its reliability and validity. Haynes (2009), measures the impact of positioning optimization on typing performance and user comfort for people with and without low back pain in alternative working postures. Meijer, Frings-Dresen and Sluiter (2009), investigate the effects of innovative office concept (e.g. open-plan, flexible workplaces and a paperless office concept) on office workers' health and performance. Luttmann, Schmidt and Jäger (2010), focus on working conditions, muscular activity, and complaints of office workers. Choobineh, Motamedzade, Kazemi, Moghimbeigi and Pahlavian (2011), investigate psychosocial risk factors and musculoskeletal symptoms among office workers. Computer use risk factors were identified in previous research and standards on office design for the chair, monitor, telephone, keyboard, and mouse (Sonne, Villalta and Andrews, 2012). Park and Han (2004), introduce fuzzy rule-based modelling for luxuriousness, balance, and attractiveness of office chairs for various user groups. Groenesteijn, Ellegast, Keller, Krause, Berger and De Looze (2012), investigate the effect of office tasks on posture and movements in field settings, and the comfort rating for chair characteristics and correlation with type of task. Menéndez, Amick, Robertson, Bazzani, Derango, Rooney and Moore (2012) and Amick, Menéndeza, Bazzani, Robertsone, Derango, Rooney and Moore (2012), evaluate the impact of a highly adjustable chair and office ergonomics training on visual symptoms.

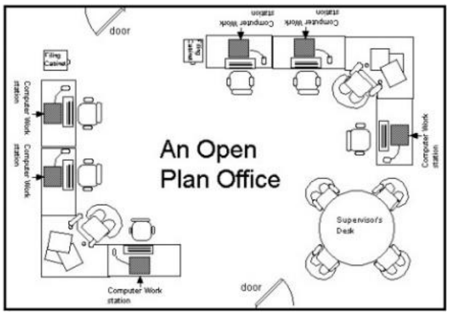
Besides the aforementioned physical environment, workplace components, the work performance for office workers are also influenced by building characteristics, office layout, and workspace. Jo and Gero (1998), develop an evolutionary model to solve a large office layout planning problem with its associated topological and geometrical arrangements of space elements. De Croon, Sluiter, Kuijer and Frings-Dresen (2005), examine how the office location (e.g. telework office versus conventional office), the office layout (e.g. open layout versus cellular office), and the office use (e.g. fixed versus shared workplaces) dimensions affect the office worker's job demands, job resources, short and long term reactions. Margaritis and Marmaras (2007), consider the workplace components, the working persons, their task requirements, the physical environment, the building characteristics, and work performance when designing the layout of office workstations. Danielsson, Chungkham, Wulf, and Westerlund (2014), investigate the effect of office type on sickness absence among office employees.

Haynes (2008-a), aims to evaluate the impact of office comfort on office occupiers' productivity and concludes that there is not a clear connection between the office layout, office occupiers' work patterns and productivity. Also, Haynes (2008-b), claim that it is not easy to measure office comfort but there are evidences that office comfort can affect productivity. Recently, Haynes, Suckley and Nunnington (2017), focus on not only the relationship between the office type and productivity but also the differences of age and gender. Pournaderi, Ghezavati and Mozafari (2019), suggests a two-objective problem which includes an objective function regarding minimization of transportation costs besides the constraints limiting the budget and transporter types. Vadivel, Sequeira and Jauhar (2019), introduces a Data Envelopment Analysis model for facility layout problem, specifically Indian Post Services. The study is also one of the recent samples of paper that propose a linkage between mathematical modelling and facility layout.

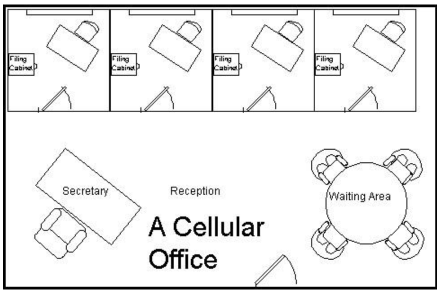
Up to best knowledge, there is no study that focuses on cell type offices and assesses comfort level of office employees. Therefore, this study aims to fill this gap in the literature.

2.2. Research setting

Depending on the office type (cellular office, cubicle office, shared-room office, small, medium-sized and large open-plan office, flex-office, and combi-office) the number and area of units and the layout can be designed in different ways. Example of layout for an open plan office is illustrated in Figure 2.a. and cellular type is illustrated in Figure 2.b.



a. Open plan



b. Cellular

Figure 2. Office Layout Examples

This study considers cellular office that corresponds to a number of cells or units within the building. Cellular office is usually for one person and is a small to medium sized room with a door and windows (where the room contains an outside wall). Montreuil et al. (1999) provides an example of fractal cellular layout as in Figure 3. The fractal design is adapted for the office layouts in this study. A layout that also meets the ergonomics requirements is designed first and then it is repeated for the cell type offices in the building.

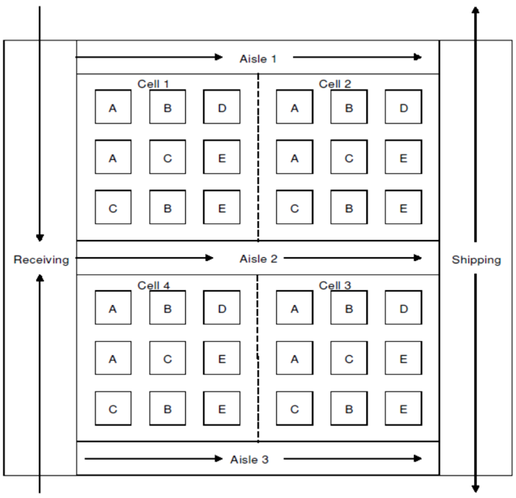


Figure 3. An Example of Fractal Cells

The general procedure is summarized in three basic steps in Figure 4.

Step1 Office employees assess environmental and physical comfort for current layout
Step2 OFFICE LAYOUT
2.1. Determine the number of units
2.2.Determine the area of units
2.3. Office employers assess the closeness values for the units in the offices
2.4. Revise and solve the mathematical model
2.5. Determine the location of the furniture
Step3 Office employers assess environmental and physical discomfort for new layout

Figure 4. Basic steps of the proposed approach

First of all, a permission for data collection has been provided by the department chair. Then, office employees are asked to assess the office they occupy in terms of environment and physical environment meet the guidelines or not. Table 1 summarizes the questions in the questionnaire. 5 Likert type scale is used to assess the answers where 1 is defined as strongly disagree and 5 strongly agree. Research and publication ethics was considered for each step of the study.

In the next step, the number of units that will be used in each office and related dimensions are identified. To generate qualitative flow measurement for the office layout design, employees are asked to define the closeness relationship values for the units as suggested in Muther (1961). The Mixed Integer Programming (MIP) originally proposed by Tompkins, White, Bozer and Tanchoco (2010), can be used to solve facility layout problems where the areas of departments/machines are not equal.

Table 1

Assessment Questions In The Questionnaire

No	Assessment questions
1	There is enough space in my office to move easily
2	I can open my office's room door widely
3	I can open my office's window widely
4	I can easily study during daytime without switching on my office's lights
5	I can easily reach my office chair
6	I can easily move through my office chair while working at my desk
7	I don't feel any disturbance due to reflection
8	The two seats in my office are easy reachable
9	I can easily open and use all the cabinets and drawers in my office
10	I am satisfied with my office's heating facility
11	I am satisfied with my office's cooling facility
12	I am satisfied with my office's air flow facility
13	I am satisfied with my office's illumination facility
14	Noise level in my office does not bother me

This study modifies and extends the constraints of this mathematical model so as to meet the ergonomic requirements and generate a layout for one cell type office. The constraints are revised based on the ergonomic requirements defined in Margaritis and

Marmaras (2007). It is stated that doors, windows, and radiators should meet the standards and determine spaces that should remain free of furniture. An area of 50 cm in front of any window, 3 m in front and 1 m at both sides of the main entrance door, 1.50 m in front and 50 cm at both sides of any other door, and 50 cm around any radiator is suggested.

3.Application and results

The steps of the fractal office layout approach are applied for the offices in a university department. Current offices are occupied by 17 full time faculty members, 8 research assistants, 1 part-time faculty, and 1 secretariat during the study. The location of the offices in the two floor building is illustrated in Figure 5. The layout of each cell type office is different from each other and many of them don't meet ergonomic requirements.

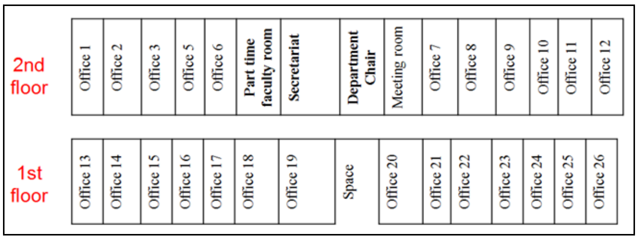


Figure 5. Representation of Office Locations

Step 1: Answers for the first ten questions and related satisfaction scores given by 25 academic staff are provided in Table 2. The arithmetic average scores for each question is calculated and presented in the last row.

Table 2

Comfort levels of office employees

No	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
1	3	4	4	1	3	3	3	3	3	3
2	3	3	4	2	3	4	1	2	2	4
3	1	3	4	4	2	2	3	2	1	5
4	3	3	1	4	3	3	3	2	4	2
5	4	3	2	2	1	1	2	2	3	2
6	3	2	2	4	4	2	4	4	2	4
7	4	2	2	4	4	3	4	1	1	4
8	1	4	3	4	2	2	3	2	3	2
9	2	4	4	3	2	1	1	2	3	5
10	4	4	1	2	3	3	3	4	4	5
11	1	3	2	1	4	3	2	2	3	5
12	1	2	1	3	4	3	2	2	3	4
13	1	3	4	4	3	2	1	2	3	4
14	3	3	4	4	3	1	4	2	2	2
15	4	3	4	2	3	2	1	4	1	5
16	3	3	1	3	1	1	2	1	4	4
17	4	3	2	3	2	4	2	4	4	5
18	4	3	2	1	4	3	2	3	2	5
19	1	4	3	4	2	4	4	1	3	3
20	1	2	1	3	1	3	1	1	3	4
21	2	1	1	4	1	4	3	2	3	5
22	4	4	2	4	3	3	4	1	3	5
23	4	2	3	3	2	1	2	4	2	3
24	2	1	2	1	1	1	3	1	3	2
25	2	3	2	1	1	2	3	2	3	5
AVG	2.60	2.88	2.44	2.84	2.48	2.44	2.52	2.24	2.72	3.88

The offices in concern are isolated from each other and located to the sides of the corridors that are not close to the classrooms. Therefore, it is not surprising that the academic staffs were not bothered about the noise level in their offices with an average value of 3.24. All the offices are located on the south part of the building and have a window that is large enough. Further, the lighting of the offices is declared to meet the guidelines and daylight is claimed to be sufficient with the average of 2.84 satisfaction level. Consequently, the average rating for lighting comfort is calculated as 3.9. The airflow, cooling, and heating average comfort values of offices are declared to be 3.56, 3.16, and 3.88 respectively. On the other hand, the staff claimed that the two seats (2.24) and their office chair (2.48) in their office were not easily reachable. Further, they may have problems while opening the office room door (2.88) and window (2.44) widely. Concerning the layout of office furniture within the office, the average satisfaction for moving easily through the office chair during working behind the desk is rated 2.44 and the overall space to move easily within the office is rated as 2.6.

An illustration of a current office layout is given in Figure 6. Although the locations of the office furniture seem proper, the reflection from the window might cause problems when studying with a computer on the desk. Since, this is the case in some of the offices; the average comfort value for reflection value is calculated as 2.52.

Step 2.1 : A workstation design is composed of the appropriate elements for the working activities, i.e., desk, seat, storage cabinets, visitors' seats and any other equipment required for the work. The study assumes that office chair and computer monitors are ergonomically designed and are adjustable.

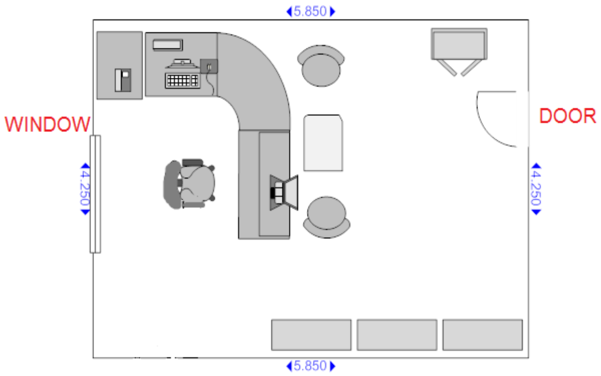
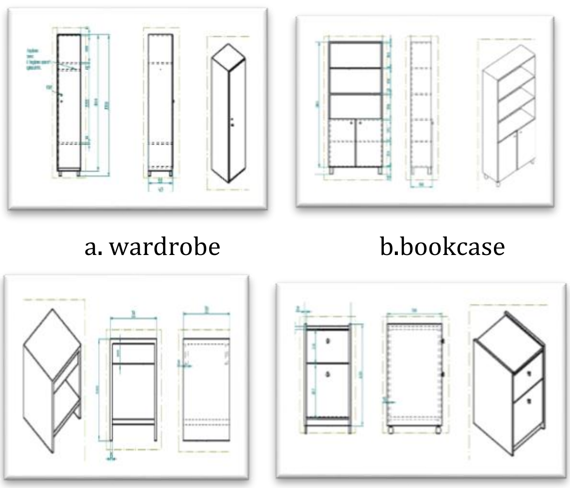


Figure 6. Representation Of A Current Layout

Examples of the office furniture in concern are illustrated in Figure 7.



a. wardrobe b.bookcase

c.coffe table d.cabinet

Figure 7. Examples of Modules In Concern

Step 2.2: The furniture and module names and whether they are movable or fixed are provided in Table 3. Further, the dimensions are presented in the last column of the table. Since there is one radiator in each office and located (fixed) just under the window, it is not considered in the model.

Table 3
Features And Allocated Dimensions Of Furniture In Concern

No	Module name	Type	Dimensions (cm)		Adding
1	Wardrobe	Moveable	50	100	Open Doors
2	Bookcase-1	Moveable	90	80	Open Doors
3	Bookcase-2	Moveable	90	80	Open Doors
4	Bookcase-3	Moveable	90	80	Open Doors
5	Seat-1	Moveable	50	70	Sitting Clearance
6	Seat-2	Moveable	50	70	Sitting Clearance
7	Coffee table	Moveable	50	50	n/a
8	Cabinet	Moveable	50	80	Open Drawers
9	Workstation	Moveable	230	160	n/a
10	Door (space)	Fixed	90	90	Open state
11	Window	Fixed	120	60	Open State

Step 2.3: Office employees are asked to evaluate and discuss the appropriate closeness values of the modules by the survey. Office workers are requested to rate the closeness as absolutely necessary (A=6), very important (E=5), important (I=4), ordinary importance (O=3), unimportant (U=2), undesirable (X=1). First, the consistency is checked and then, based on the average points given, the closeness values for the office furniture are assigned as stated in Table 4.

Table 4

Closeness Values For The Units In The Offices

No	Unit name	1	2	3	4	5	6	7	8	9	10	11
1	Wardrobe	-										
2	Bookcase-1	O	-									
3	Bookcase-2	O	E	-								
4	Bookcase-3	O	U	E	-							
5	Seat-1	I	O	O	O	-						
6	Seat-2	I	O	O	O	O	-					
7	Coffee table	O	O	O	O	O	A	-				
8	Cabinet	O	O	O	O	A	O	O	-			
9	Work station	O	U	U	U	A	U	U	A	-		
10	Door (space)	E	U	U	U	A	U	U	U	O	-	
11	Window	X	X	X	X	E	I	I	U	O	U	-

Step 2.4: The parameters of the model are listed as follows:

- Dimensions of the room:
  SLx: The side length on the x axis of the room

SLy: The side length on the y axis of the room

- Dimensions of the furniture:
  - Wt(i): width of furniture i   i=1, 2, …, 11
  - Lt(i): length of furniture i   i=1, 2, …, 11
- fi, j : closeness ratings between furniture i and j

The furniture dimensions in the model are defined by considering their actual dimensions and the space requirements to meet an ergonomic environment. The bookcases have closets below the shelves. Therefore, the dimensions such as Lt(2), Lt(3), and Lt(4) are considered as the total length of the shelves and the length of the closet when the board doors are widely open. Similar situations exist for the wardrobe and cabinet as well. For the seats, the distance between buttock and knee while sitting (dimension E) is considered as shown in Figure 8 (Allsteel and Allsteel, 2006).

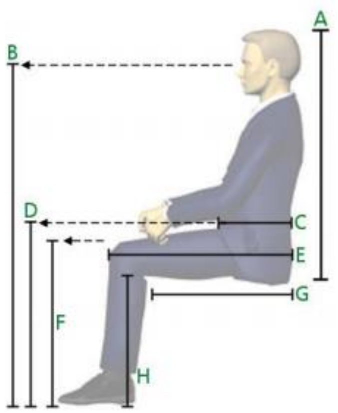


Figure 8. Representation of Clearance When Sitting

The locations of the door and window in each office are defined as fixed. However, the values of length for these fixed elements are considered when they are widely opened. A 80 cm distance between the wall and the table unit of the workstation module is stated to enable the office employee move comfortably while working.

The decision variables are defined as follows:

- Rx(i): x-coordinate of the right side of furniture i, i=1, 2, …, 11
- Lx(i): x-coordinate of the left side of furniture i, i=1, 2, …, 11
- Uy(i): y-coordinate of the upper side of furniture i, i=1, 2, …, 11
- By(i): y-coordinate of the lower side of furniture i, i=1, 2 ,…, 11
- K(i,p)= 1, if furniture i takes the position p, 0 otherwise   i=1, 2 ,…, 11; p=1, 2 , 3, 4

The position p, represents the location of a module and a wall. As illustrated in Figure 9, p is assigned one of the predefined values, based on the wall-furniture location in an office layout area.

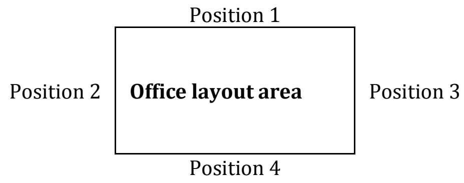


Figure 9. Representation of Available Locations For The Module

The objective for office layout problem is to minimize the flow between the office elements (furniture). The whole model is presented in Appendix 1. According to the model, constraint (2) states the total area. Constraints (3), (4), and (5) ensure the placement of the window, Constraints (6), (7), (8), and (9) ensure the placement of the door that is defined as a fixed element. Constraint (10) and Constraint (11) guarantee the position of the door and the window respectively. Constraint (12) states the position of the workstation. It avoids the workstation to be placed at position 1 and 4 because of the ergonomic considerations relevant to office door movements and sunshine reflection on the monitor. Constraints (13), (14), (15), and (16) force the moveable office elements lean to the relevant walls. Thus, the open space of the office can be expanded for the user. Constraints (17), (18), (19), and (20) make the elements stay in the usable office area. Constraints (21) and (22) state the centroids of the each office element. Constraint (23) guarantees that each element can take only one position. Constraints (24), (25), (26), and (27) are constraints enable the total dimensions not to exceed the length of the relevant wall. Constrains (28), (29), (30), (31), (32), and (34) ensure the directions of the office elements according to their positions. All elements are positioned to ease usability. Constrains (35), (36), and (37) avoid overlaps between the furniture at the same wall. M is defined as a very big number and Constraints (38), (39), (40), (41), (42), and (43) avoid overlaps between the furniture at the adjacent walls.

Based on the module considered in the office, the constraints meet the following ergonomic requirements: an area of 55 cm along the front side of the desk or the outer edge of the visitor’s seat, an area of 50 cm along the entry side of the workstation, an area of 75 cm along the back side of the desk (seat side), an area of 100 cm along the back side of the desk, if there are storage cabinets behind the desk.

Step 2.5: The model is solved through DIscrete and Continuous OPTimizer (DICOPT) solver of GAMS. Best integer solution is obtained as the objection function value is z = 87860, where the duration is 10.97 seconds. Figure 10 represents the best layout obtained from the solution of MIP model considering ergonomic requirements.

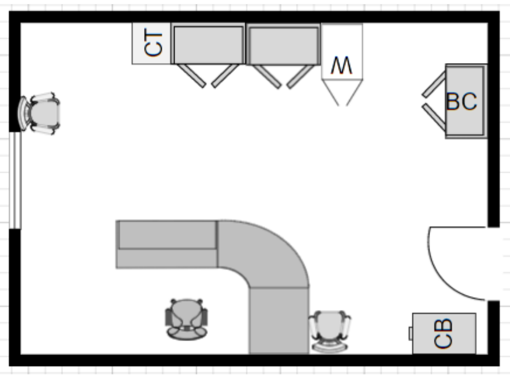


Figure 10. The Office Layout Obtained From The MIP Model Solution

Step 3: The office layout designed by considering the closeness ratings defined by office employees along with the redefined constraints is discussed with the potential users. Unexceptional positive feedbacks attained through focus group interviews encouraged the decision makers to adapt the layout for each office in the building. Office employees especially highlighted the wider space in the center of the offices and easier use of furniture. Resulting layout of the department will be structured as fractal layout with the replication of the two dimensional layout generated by the mathematical model. The fractal office layout does not only satisfy office employees but also the maintenance staff. It is declared that similar locations of units would ease and shorten the maintenance activities in an office.

5. Conclusions

It is important to consider the comfort levels of the office employees for it may affect the job satisfaction in the long term. Constrains included in the MIP model consider basic ergonomic requirements. However, the proposed model is not able to include any constraints related with lighting and noise. On the other hand, the model can easily be revised to generate layouts for other cell type offices by redefining the number and dimensions of the units and office dimensions. It is also possible to make interviews with office employees when defining the closeness ratings. This study does not consider monitor and keyboard location on the work surfaces and give more importance on the unit layout within the office. Additionally, since the building considered in this study has identical offices with doors and windows that are positioned in the same way, the proposed model has constraints just to fix the positions of windows and doors. In different scenarios such as various positions of window and doors, the model will need to be updated.

In the cases where the heating, cooling, or illumination systems are problematic, the building structure and relations with the layout can be considered in a wider perspective by including architects and mechanical engineers to the research team. The assumptions related with the physical locations of heating and electricity equipment, the orientation of furniture, and alternative lightning can also be considered in the following studies.

Acknowledgements

We would like to present our appreciation to all survey participants who made easier data collection.

Contribution of Researchers

In this study, N. Fırat ÖZKAN completed literature review and data collection while Berna HAKTANIRLAR ULUTAŞ prepared the mathematical model.

Conflict of Interest

No conflict of interest was declared by the authors.

References

Allsteel, S.O. & Allsteel, E.T. (2006). *Ergonomics and Design a Reference Guide. Muscatine (IO):* Iowa, USA Allsteel Incorporation.

Amick, B.C., Menéndeza, C.C., Bazzani, L., Robertsone, M., Derango, K., Rooney, T., & Moore, A. (2012). A Field Intervention Examining the Impact of an Office Ergonomics Training and a Highly Adjustable Chair on Visual Symptoms in a Public Sector Organization. *Applied Ergonomics,* 43, 625-631. doi: https://doi.org/10.1016/j.apergo.2011.09.006

Anjos, M.F. & Vieira, M.V.C. (2017). Mathematical Optimization Approaches for *Facility Layout* Problems: the State-of-the-Art and Future Research Directions. *European Journal of Operational Research,* 261, 1-16. doi: https://doi.org/10.1016/j.ejor.2017.01.049

Banbury, S.P. & Berry, D.C. (2005). Office Noise and Employee Concentration: Identifying Causes of Disruption and Potential Improvements. *Ergonomics,* 48(1), 25-37. doi: https://doi.org/10.1080/00140130412331311390

Bergqvist, U., Wolgast, E., Nilsson, B., & Voss, M. (1995). Musculoskeletal Disorders Among Visual Display Terminal Workers: Individual, Ergonomic, and Work Organizational Factors. *Ergonomics,* 38, 763–776. doi: https://doi.org/10.1080/00140139508925148

Choobineh, A., Motamedzade, M., Kazemi, M., Moghimbeigi, A. , & Pahlavian, A.H. (2011). The

İmpact of Ergonomics Intervention on Psychosocial Factors and Musculoskeletal Symptoms among Office Workers. International Journal of Industrial *Ergonomics,* 41, 671-676. doi: https://doi.org/10.1016/j.ergon.2011.08.007

Coluci, M.Z.O., Alexandre, N.M.C., & Rosecrance, J. (2009). Reliability and Validity of an Ergonomics-Related Job Factors Questionnaire. *International Journal of Industrial Ergonomics*, 39, 995-1001. doi: https://doi.org/10.1016/j.ergon.2009.08.011

Danielsson C.B., Chungkham H.S., Wulff C., & Westerlund H. (2014). Office Design's Impact on Sick Leave Rates. *Ergonomics.* 57(2), 139-147. doi: https://doi.org/10.1080/00140139.2013.871064

De Croon, E., Sluiter, J., Kuijer, P.P., & Frings-Dresen, M. (2005). The Effect of Office Concepts on Worker Health and Performance: a Systematic Review of the Literature. *Ergonomics,* 48(2), 119-134. doi: https://doi.org/10.1080/00140130512331319409

Delisle, A., Larivière, C., Plamondon, A., & Imbeau, D. (2006). Comparison of Three Computer Office Workstations Offering Forearm Support: Impact on Upper Limb Posture and Muscle Activation. *Ergonomics,* 49(2), 139-160*.* doi: https://doi.org/10.1080/10610270500450739

Drira*,* A., Pierreval, H., & Hajri-Gabouj, S., (2007). *Facility Layout* Problems*:* A Survey. *Annual* Reviews *in Control,* 31(2): 255-267. doi: https://doi.org/10.1016/j.arcontrol.2007.04.001

Durmusoglu, M. B. & Kulak, O. (2008). A methodology for the design of office cells using axiomatic design principles. *Omega*, 36(4), 633-652.

Groenesteijn, L., Ellegast, R.P., Keller, K., Krause, F., Berger, H., & De Looze, M.P. (2012). Office Task Effects on Comfort And Body Dynamics in Five Dynamic Office Chairs. *Applied Ergonomics,* 43, 320-328. doi:https://doi.org/10.1016/j.apergo.2011.06.007

Hales, T.R., Sauter, S.L., Peterson, M.R., Fine, L.J., Putz-Anderson, V., Schleifer, L.R., Ochs, T.T., & Bernard, B.P. (1994). Musculoskeletal Disorders Among Visual Display Terminal Users in a Telecommunications Company. *Ergonomics,* 37, 1603–1621.

Haynes B., Suckley L., & Nunnington N. (2017). Workplace Productivity and Office Type: an Evaluation of Office Occupier Differences Based on Age and Gender. *Journal of Corporate Real Estate,* 19(2), 111-138. doi: https://doi.org/10.1108/JCRE-11-2016-0037

Haynes, B. (2008-a). The Impact of Office Layout on Productivity. *Journal of Facilities Management,* 6(3), 189-201. doi: https://doi.org/10.1108/14725960810885961

Haynes, B. (2008-b). The Impact of Office Comfort on Productivity. *Journal of Facilities Management,* 6(1), 37-51. doi: https://doi.org/10.1108/14725960810847459

Haynes, S. (2009). Effects of Positioning Optimization in an Alternative Computer Workstation for People with and without Low Back Pain. *International Journal of Industrial Ergonomics,* 39, 719-727. doi: https://doi.org/10.1016/j.ergon.2009.05.001

Hünting, W., Laubli, T., & Grandjean, E. (1981). Postural and Visual Loads at VDT Workplaces. I. Constrained Postures. *Ergonomics,* 24, 917–931.

Jo, J.H. & Gero, J.S. (1998). Space Layout Planning Using an Evolutionary Approach. *Artificial Intelligence in Engineering,* 12, 149-162.

Joines, S.M.B. & Sommerich, C.M. (2001). Comparison of Self-Assessment and Partnered-Assessment as Cost-Effective Alternative Methods for Office Workstation Evaluation. *International Journal of Industrial Ergonomics,* 28, 327–340.

Kaarlela-Tuomaala, A., Helenius, R., Keskinen, E., & Hongisto, V. (2009). Effects of Acoustic Environment on Work in Private Office Rooms and Open-Plan Offices – Longitudinal Study during Relocation. *Ergonomics,* 52(11), 1423-1444. doi: https://doi.org/10.1080/00140130903154579

Küller, R., Ballal, S., Laike, T., Mikellides, B., & Tonello, G. (2006). The Impact of Light and Colour on Psychological Mood: A Cross-Cultural Study of Indoor Work Environments. *Ergonomics,* 49(14), 1496-1507.doi: https://doi.org/10.1080/00140130600858142

Lan, L., Lian, Z., & Pan, L. (2010). The Effects of Air Temperature on Office Workers' Well-Being, Workload and Productivity-Evaluated with Subjective Ratings. *Applied Ergonomics,* 42, 29-36*.* doi: https://doi.org/10.1016/j.apergo.2010.04.003

Lee, J. Y. Wargocki, P. Chan, Y. H. Chen, L. & Tham, K. W. (2020). How does indoor environmental quality in green refurbished office buildings compare with the one in new certified buildings?. *Building and Environment*, 2020, 106677. doi: https://doi.org/10.1016/j.buildenv.2020.106677

Luttmann, A., Schmidt, K.H., & Jäger, M. (2010). Working Conditions, Muscular Activity and Complaints of Office Workers. *International Journal of Industrial Ergonomics,* 40, 549-559. doi: https://doi.org/10.1016/j.ergon.2010.04.006

Margaritis, S. & Marmaras, N. (2007). Supporting the Design of Office Layout Meeting Ergonomics Requirements. *Applied Ergonomics,* 38, 781-790. doi: https://doi.org/10.1016/j.apergo.2006.10.003

Meijer, E.M., Frings-Dresen, M.H.W., & Sluiter, J.K. (2009). Effects of Office Innovation on Office Workers' Health and Performance. *Ergonomics,* 52(9), 1027-1038.

Menéndez, C.C., Amick, B.C., Robertson, M., Bazzani, L., Derango, K., Rooney, T., & Moore, A. (2012). A Replicated Field Intervention Study Evaluating the Impact of a Highly Adjustable Chair and Office Ergonomics Training on Visual Symptoms. *Applied Ergonomics,* 43, 639-644. doi: https://doi.org/10.1016/j.apergo.2011.09.010

Montreuil, B., Venkatadri, U., & Rardin, R.L. (1999). Fractal Layout Organization for Job Shop Environments. *International Journal of Production Research,* 37(3), 501-521.

Muther, R. (1961). *Systematic Layout Planning*. Boston, USA: Industrial Education Institute.

Park, J. & Han, S.H. (2004). A Fuzzy Rule-Based Approach to Modeling Affective User Satisfaction towards Office Chair Design. *International Journal of Industrial Ergonomics,* 34, 31–47. doi: https://doi.org/10.1016/j.ergon.2004.01.006

Pournaderi, N., Ghezavati, V. R., & Mozafari, M. (2019). Developing a mathematical model for the dynamic facility layout problem considering material handling system and optimizing it using cloud theory-based simulated annealing algorithm. *SN Applied Sciences*, *1*(8), 832. doi: https://doi.org/10.1007/s42452-019-0865-x

Robertson, M.M., Huang, Y.H., O'Neill, M.J., & Schleifer, L.M. (2008). Flexible Workspace Design and Ergonomics Training: Impacts on the Psychosocial Work Environment, Musculoskeletal Health, and Work Effectiveness among Knowledge Workers. *Applied Ergonomics,* 39, 482– 494. doi: https://doi.org/10.1016/j.apergo.2008.02.022

Sauter, S.L., Schleifer, L.M., & Knutson, S.J. (1991). Work Posture, Workstation Design, and Musculoskeletal Discomfort in a VDT Data Entry Task. *Human Factors,* 33, 151–167.

Shahzad, S., Brennan J., Theodossopoulos D., Hughes B, & Calautit J.K. (2017). A Study of the Impact of Individual Thermal Control on User Comfort in the Workplace: Norwegian Cellular Vs. British Open Plan Offices. *Architectural Science Review,* 60(1), 49-61. doi:https://doi.org/10.1080/00038628.2016.1235544

Sonne, M., Villalta, D.L., & Andrews, D.M. (2012). Development and Evaluation of an Office Ergonomic Risk Checklist: ROSA - Rapid Office Strain Assessment. *Applied Ergonomics,* 43, 98-108. doi: https://doi.org/10.1016/j.apergo.2011.03.008

Stewart, T. (1985). Ergonomics of the Office. *Ergonomics,* 28(8), 1165-1177.

Szetoa, G.P.Y., Straker, L.M., & O'Sullivan, P.B. (2005). The Effects of Speed and Force of Keyboard Operation on Neck–Shoulder Muscle Activities in Symptomatic and Asymptomatic Office Workers. *International Journal of Industrial Ergonomics,* 35, 429–444. doi: https://doi.org/10.1016/j.ergon.2004.10.009

Tompkins, J.A., White, J.A., Bozer, Y.A., & Tanchoco, J.M.A. (2010). *Facilities Planning.* Hoboken, USA: John Wiley & Sons Ltd.

Toomingas, A. and Gavhed, D. (2008). Workstation Layout and Work Postures at Call Centres in Sweden in Relation to National Law, EU-Directives and ISO-Standards, and to Operators' Comfort and Symptoms. *International Journal of Industrial Ergonomics,* 38, 1051-1061. doi: https://doi.org/10.1016/j.ergon.2008.02.010

Vadivel, S. M., Sequeira, A. H., & Jauhar, S. K. (2018). Metaheuristic for optimize the india speed post facility layout design and operational performance based sorting layout selection using DEA method. *International Conference on Intelligent Systems Design and Applications* , 1035-1044, Cham. doi: http://10.1007/978-3-030-16660-1_101

Venkatadri, U., Rardin, R. L., & Montreuil, B. (1997). A Design Methodology for Fractal Layout Organization. *IIE Transactions,* 29, 911–924. doi: https://doi.org/10.1080/07408179708966411

Appendix 1. Optimization Model

$$Min \sum_i \sum_j f(i,j) \times (|\alpha(i) - \alpha(j)| + |\beta(i) - \beta(j)| \quad (1)$$

Subject to:

$$\sum_{i=1}^{11} \left(\left((Rx(i) - Lx(i)) * (Uy(i) - By(i)) \right) \leq SLx \times SLy \quad (2)$$

$$Rx(11) = Wt(11) + Lx(11) \quad (3)$$

$$Lx(11) = 100 \quad (4)$$

$$By(11) = Uy(11) - Lt(11) \quad (5)$$

$$Rx(10) = Wt(10) + Lx(10) \quad (6)$$

$$Lx(10) = 50 \quad (7)$$

$$Uy(10) = By(10) + Lt(10) \quad (8)$$

$$By(10) = 0 \quad (9)$$

$$K(10,4) = 1 \quad (10)$$

$$K(11,1) = 1 \quad (11)$$

$$K(9,4) + K(9,1) = 0 \quad (12)$$

$$M \times (1 - K(i,1)) + Uy(i) \geq SLy, \quad for\ all\ i \quad (13)$$

$$M \times (1 - K(i,2)) + Lx(i) \leq 0, \quad for\ all\ i \quad (14)$$

$$M \times (1 - K(i,3)) + Rx(i) \geq SLx, \quad for\ all\ i \quad (15)$$

$$M \times (1 - K(i,4)) + By(i) \leq 0, \quad for\ all\ i \quad (16)$$

$$Rx(i) \geq Lx(i), \quad for\ all\ i \quad (17)$$

$$Rx(i) \leq SLx, \quad for\ all\ i \quad (18)$$

$$Uy(i) \geq By(i), \quad for\ all\ i \quad (19)$$

$$Uy(i) \leq SLy, \quad for\ all\ i \quad (20)$$

$$\alpha(i) = 0.5 \times Rx(i) + 0.5 \times Lx(i), for\ all\ i \quad (21)$$

$$\beta(i) = 0.5 \times Uy(i) + 0.5 \times By(i), for\ all\ i \quad (22)$$

$$\sum_{p=1}^{4} K(i,p) = 1, for\ all\ i \quad (23)$$

$$\sum_{i=1}^{11} ((Rx(i) - Lx(i)) \times K(i,1)) \leq SLx \quad (24)$$

$$\sum_{i=1}^{11} ((Rx(i) - Lx(i)) \times K(i,4)) \leq SLx \quad (25)$$

$$\sum_{i=1}^{11} ((Uy(i) - By(i)) \times K(i,2)) \leq SLy \quad (26)$$

$$\sum_{i=1}^{11} ((Uy(i) - By(i)) \times K(i,3)) \leq SLy \quad (27)$$

$$Rx(i) - Lx(i) \leq M \times (1 - (K(i,1) + K(i,4)) + Wt(i), for\ all\ i \quad (28)$$

$$Rx(i) - Lx(i) \leq M \times (1 - (K(i,2) + K(i,3)) + Lt(i), for\ all\ i \tag{29}$$

$$Uy(i) - By(i) \leq M \times (1 - (K(i,1) + K(i,4)) + Lt(i), for\ all\ i \tag{30}$$

$$Uy(i) - By(i) \leq M \times (1 - (K(i,2) + K(i,3)) + Wt(i), for\ all\ i \tag{31}$$

$$Rx(i) - Lx(i) \geq (Wt(i) \times (K(i,1) + K(i,4)) + Lt(i) \times (K(i,2) + K(i,3)), for\ all\ i \tag{32}$$

$$Uy(i) - By(i) \geq (Wt(i) \times (K(i,2) + K(i,3)) + Lt(i) \times (K(i,1) + K(i,4)), for\ all\ i \tag{33}$$

$$|\alpha(i) - \alpha(j)| \times (K(i,1) \times K(j,1)) \geq \left(0.5 \times (Rx(i) - Lx(i))\right) + \left(0.5 \times (Rx(j) - Lx(j))\right) - M \times \left(1 - (K(i,1) \times K(j,1))\right) for\ all\ i\ and\ j, i \neq j \tag{34}$$

$$|\beta(i) - \beta(j)| \times (K(i,1) \times K(j,1)) \geq \left(0.5 \times (Uy(i) - By(i))\right) + \left(0.5 \times (Uy(j) - By(j))\right) - M \times \left(1 - (K(i,2) \times K(j,2))\right) for\ all\ i\ and\ j, i \neq j \tag{35}$$

$$|\beta(i) - \beta(j)| \times (K(i,3) \times K(j,3)) \geq \left(0.5 * (Uy(i) - By(i))\right) + \left(0.5 \times (Uy(j) - By(j))\right) - M \times \left(1 - (K(i,3) \times K(j,3))\right) for\ all\ i\ and\ j, i \neq j \tag{36}$$

$$|\alpha(i) - \alpha(j)| \times (K(i,4) \times K(j,4)) \geq \left(0.5 \times (Rx(i) - Lx(i))\right) + \left(0.5 \times (Rx(j) - Lx(j))\right) - M \times \left(1 - (K(i,4) \times K(j,4))\right) for\ all\ i\ and\ j, i \neq j \tag{37}$$

$$M \times (1 - (K(i,1) \times K(j,4)) + By(i) \geq Uy(j)\ \ for\ all\ i\ and\ j, i \neq j \tag{38}$$

$$M \times (1 - (K(i,1) \times K(j,2)) + By(i) \geq Uy(j)\ \ for\ all\ i\ and\ j, i \neq j \tag{39}$$

$$M \times (1 - (K(i,1) \times K(j,3)) + By(i) \geq Uy(j)\ \ for\ all\ i\ and\ j, i \neq j \tag{40}$$

$$M \times (1 - (K(i,3) \times K(j,2)) + Lx(i) \geq Rx(j)\ \ for\ all\ i\ and\ j, i \neq j \tag{41}$$

$$M \times (1 - (K(i,3) \times K(j,4)) + By(i) \geq Uy(j)\ \ for\ all\ i\ and\ j, i \neq j \tag{42}$$

$$M \times (1 - (K(i,2) \times K(j,4)) + By(i) \geq Uy(j)\ \ for\ all\ i\ and\ j, i \neq j \tag{43}$$