A Pre-Evaluation Tool for Interior Designs of High-Rise Office Buildings by User Movement Simulation after Covid'19

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Abstract. User movement optimization has become a more crucial design parameter in high-rise office interior design after the Covid'19 pandemic. This study aims to develop a pre-evaluation tool using vertical and horizontal user movement simulation in a high-rise building; to guide the pre-design phase of an office interior. Agent-based simulation software (AnyLogic v8.7.10) analyzes the relationship between circulation, design elements, and space. First, initial design which is created by the interior design team is evaluated by this simuation; later different interior design alternatives are simulated and tested to compare the results. Therefore, early design decisions taken by the design team are subject to change, reducing user intensity in specific locations throughout the day. This study concluded that the simulations' results can be integrated into the design decisions by the design team to develop effective interior designs led by new office design parameters after Covid'19.

Keywords: Agent-based systems, Office design, High-rise building, Covid'19, Interior design

1 Introduction

To optimize the movement-based design principles after Covid'19, the new office design parameters need to be set forth. Since there are many studies on office design optimization (Boje, Li, 2018), building occupancy simulation (Rai, Hu, 2018), agent based systems (Muravev, 2021; Norouziasl, 2020; Luo et al., 2017), pedestrian traffic (Rodriguez et al., 2013), ant colony optimization (Guarnizo, Pineda, 2019), elevator traffic (So, Al-Sharif, 2015) and wayfinding (Kuliga et al. 2019; Vilar et al., 2012; Hölscher et al. 2009); there are few research (Lee et al. 2021; Kelsey, 2021; Gomez et al. 2021) on the means of new working habits and user movement after Covid'19 pandemic.

This pandemic condition added new dimensions to an already complex design problem. With the Covid-19 pandemic, user movements have changed office life, creating new working habits and rules. Designers must consider the spread risk of viruses in the air and surface. To reduce virus spread, examining a multi-story structure and simulating it according to user movement is necessary. Most studies on agent-based simulation performance have focused on isolated floor levels in the horizontal plane (Hölscher et al., 2006). In a multi-story building, it is necessary to examine its relationship with other floors, vertically and horizontally to analyze the user's movement. This manuscript aims to offer new interior design simulations in a multi-level building while considering the interior design decisions.

The case study was carried out in an office building which is still under construction in Istanbul Financial Center with 2,500 employees and 17 directorates (35.000 sqm), total of 17 floors. The interior design layout of this office building is assigned to an architectural design office. Within this manuscript, authors used an agent-based simulation model to test the initial design layout, simulating the high-rise office building's vertical and horizontal user movement. To limit the study, this case study has been conducted between 12^{th} and 13^{th} floors, designed to host the Technical Vice Presidency Department (Table 1), a total of 385 employees. Later, the results of the simulations and the design suggestions are presented to the design office; new alternatives are simulated and compared according to the criteria; total distance, time, speed, and user density.

2 Movement-Based Design Studies and New Office Design

User movement is one of the most significant parameters affecting building traffic. Although recent work on crowd simulation focuses on public zones (Lu et al., 2016), it is challenging to simulate and examine large crowds in real-time because the agents are not programmed to make independent decisions. The model should consider both, dealing with individual human movement and interactions between them (Boje, Li, 2018). Other academic work has also been produced to develop models to simulate user movements with agent and graph-based applications (Rai, Hu, 2018). Within this perspective, agent-based modeling is also found useful and practical as a method for this study.

Interior design decisions that affect user movement should be reconsidered to optimize building traffic. The primary step in modeling and simulating occupancy behavior is collecting and monitoring user data (Park et al., 2019). To collect and analyze these data, user movement parameters must be measured.

These parameters have been divided into three major categories: (i) users' presence and absence or the number of people in space; (ii) users' location within a space; and (iii) users' preferences, energy-related behaviors, and interactions with the building (Naylor et al., 2018). Moreover, the Covid’19 pandemic, which has affected millions' lives, caused new social distance rules, personal interactions and eventually changed our working habits (Lee et al. 2021). This pandemic has altered personal interactions and hybrid working became the new normal. Physical distance between individuals is considered a key strategy for limiting Covid’19 transmissions among various mitigation measures (Matrajt and Tiffanny 2020, Nediari et al. 2021). Physical-distancing intervention is the most effective strategy for dealing with recurring infectious diseases. (Caley et al. 2008; Kleczkowski et al. 2015; Dascalu et al. 2020; Harweg et al. 2020). Therefore, it is crucial to rethink on office interiors within the social distance parameters.

After studying the office interiors both in literature and on-site projects, it is revealed that the most important design criteria to be considered in post-pandemic office designs are:

- Designing open spaces next to working areas for fresh air,
- Expanding sports fields to encourage employees to take action,
- Effective handling of ventilation per the number of employees
- Designing all spaces with automatic doors and hygienic surfaces,
- Reducing the density in the building by creating a hybrid working order with flexible working hours.
- Widening circulation areas,
- Expanding social spaces,
- Encouraging people to use stairs,
- Isolation and diversification of group work areas,
- Ensuring social distance rules.

The last five criteria are primarily used to evaluate the alternative plan layouts.

3 Methodology

Based on the key findings described in the previous section, this research aims to test a methodology for simulating the users' movement to optimize high density zones. In office buildings, where human density and movement are high, a solution proposal has been presented in order to reduce the high density during the Covid-19 pandemic process. This pandemic impacted on new office design layout, and how they can be adapted to the new normal. According to World Health Organization Exposure to COVID-19 at work zones depends on the likelihood of people coming within 1 meter of each other, constant physical contact with people who may be infected with COVID-19, and contact with contaminated objects.

In this study, a high-rise office building which is still under construction, located in Istanbul Financial Center is taken as a case study. Two floors, 12th and 13th, is simulated to limit the study. Relevant user data is taken from the insurance company, which will occupy this building for the next 20-30 years (Table 1).

As an agent-based design tool, AnyLogic v8.7.10, a program that allows the movements of agents to be observed in a system where floor plans can be input as input, is decided to be used. The flow chart of the method is explained below in (Fig.1). The user and obstacle types are defined. Obstacles are defined as the building core, walls, obstacles in the furnishing, etc., where user types are defined as workspace, entry-exit nodes, queue and waiting zones, floor, and speed. After this point, vertical and horizontal movements are coded.

As in the method, the initial plan designed by the design office is simulated. Then, some changes in the plans are made, different alternatives are created depending on the social distance parameters, which were mentioned before. As a result, all the alternatives are evaluated depending on the total distance, time, and speed parameters.

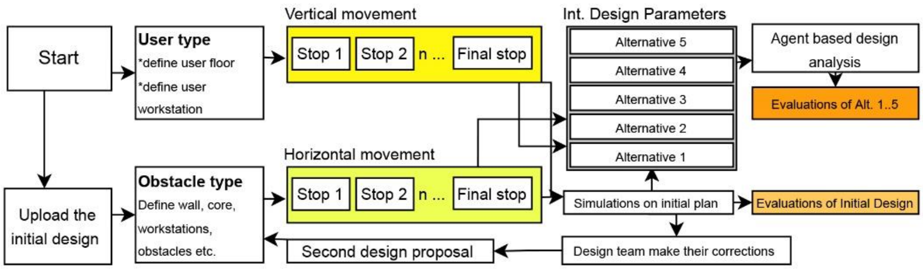

Figure 1. Flowchart of the method

3.1 Case Study: High Rise Office Interior Design at IFC

The 17-floor office building's floor plans in the Istanbul Financial Center (IFC) have been tested to evaluate its interior design decisions with user interaction. A semi-governmental insurance company will work in this building with 2000 people on 35.000 sqm. The interior design project is expected to finish by August 2022.

To develop a movement analysis in Anylogic, this work is limited to the vertical and horizontal movement between two floors. The movements of the 12th (148 people) and 13th floors (237 people) as simulated, assuming that it is a multi-story building and that the interaction between floors is also important. All employees arrive on campus at approximately the same time. The reason for choosing these two floors is that the employees are related, and the circulation is expected to be high. All employees' work zones are defined in the examined floor plans, and color codes define different departments (Fig. 2).

Agents are defined with the following attributes: Movement diameter, speed, role, start points, activity points, and exit points. There are three types of agents, one moves horizontally on the 12th, the other horizontally on the 13th, and the last type moves vertically between two floors.

Table 1. The Divisions of Technical Vice Presidency Depart. on 12th and 13th floors

		Director	Dept. head	Personel
12th floor	Directorate of Non-Vehicle Insurance	1		
	(T-12-A) Head of Operations 1 Term Insurance		1	18
	(T-12-B) Head of Operations 2 Term Insurance		1	28
	(T-12-C) Head of Indv. Non-Vehicle Ins. and Product Dev.		1	11
	(T-12-D) Head of Construction and Energy Insurance		1	12
	(T-12-E) Head of Transportation Insurance		1	19
	Directorate of Auto, Agriculture and Actuary	1		
	(T-12-F) Head of Financial Insurance		1	19
	(T-12-G) Head of Agriculture Insurance		1	8
	(T-12-H) Head of Auto Insurance and Product Dev.		1	17
	(T-12-I) Head of Actuary, Data Analysis and Reports		1	11
	(T-12-J) Head of Auto Tariff Man., Reports and Traffic Ins.			
	Reserv Seat			13
	Total			**148**
13th floor	Directorate of Operations and Risk Engineering	1		
	(T-13-A) Head of Bank Operations		1	129
	(T-13-B) Head of Agent Operations		1	35
	(T-13-C) Head of Risk Engineering		1	15
	Directorate of Reasurance and Corporate Technics	1		
	(T-13-D) Head of Corporate Technics and Sales		1	23
	(T-13-E) Head of Directly Related Institutions		1	3
	(T-13-F) Head of Reasurance and Special Risks		1	9
	(T-13-G) Head of Corporate Sales (Life and Retirement)		1	7
	Reserv Seat			7
	Total			**237**

Figure 2. The plan layout of 12th (left) and 13th (right) floors (north is upwards).

3.2 Simulation Setup

The people on the 12th and 13th floor to be simulated are placed in your floor plan according to the given work schedule. The probable action scenario is simulated with the obstacles defined to the agents that comply with this program. The agents reach the destination by passing the obstacles according to the scenario. The result of this simulation gives us the output of the distances traveled and the human density that may occur.

3.3 User Simulation Interface

To simplify simulation of the proposed framework, it is assumed that all employees first enter the building, some stop by the cloakroom, and then move to their workstations. While the scenario is being simulated, the density map is created and the movement of the agents is observed. With the inputs entered into the AnyLogic program, the speeds of the agents, their destinations (workstations), and obstacles in the overall plan are defined.

When creating a new model, the New toolbar button is clicked, and the New Model wizard appears. One should specify the name and the location where the model files need to be stored. After that, *minutes* is selected as the model time units and you finish to complete the process. After the new model is created, it already has one agent type called *Main* and an experiment called *Simulation*. Agents are the main building blocks of the AnyLogic model. In this case the *Main* agent is where all the logic of the model is defined, plan drawing of the office is uploaded and the flow chart describing the user flow process is defined (Fig. 3).

When you want to add a drawing to the interface; *entry, target, elevator lines* and *obstacles* (walls, core of building, desks, columns) are defined so that the route can be simulated and agents can move.

The process flowchart of AnyLogic defines user movement. The first step in the flowchart is *PedSource*, which creates the start point of the simulation. *PedSource* generates agents at the intended location (elevator zones). *PedSelectOutput* directs agents to their zones in specified conditions. *PedGoTo* defines the exit point of agents, which is the elevator zone. *PedChangeLevel* directs pedestrians to a different level. *PedWait* brings pedestrians to wait for a specified time in a specified location. *PedSink* finishes the simulation. When the simulation is started, the agents spawn in the defined area and begin to move to their target points. Agents notice each other and obstacles, then move at a desired speed without touching them. When they arrive at their workstation, they wait there for the time defined in the flow chart (Fig. 4).

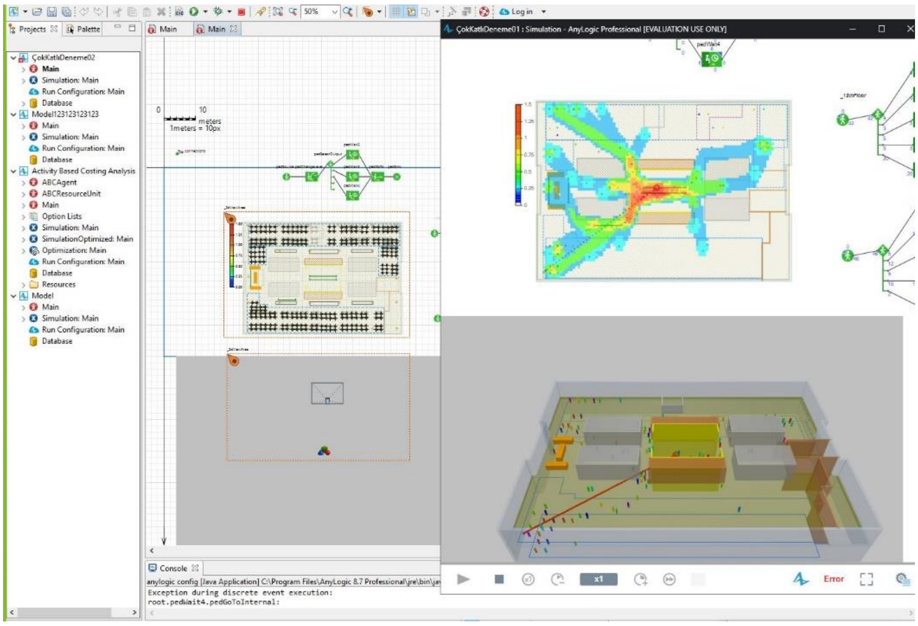

Figure 3. Anylogic v8. simulation interface

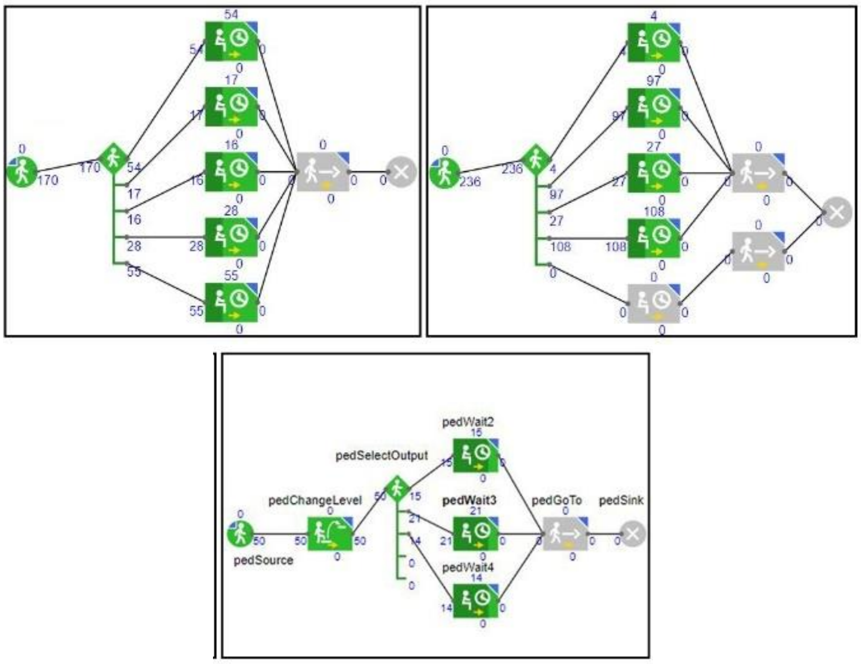

Figure 4. Anylogic coding for simulations, (left) 12th floor, (middle) 13th floor, (right) inbetween floors

4 Results

After the simulation setup is ready, the initial design is first tested, and the results can be seen in Figure 5. The color code shows that person/m2, red shows 1.5 person per m^2. After the Covid'19 pandemic, it is found that the overall density should be one person (10 m^2). The people are assumed to reach their floor via eight elevators or stairs in the core and then reach their workstations. In this simulation, we see that there are high densities in the social corner (in the west wing), therefore, more social corners should be designed.

In Alternative 1, the cloakroom's location is changed, and put in the middle of the plan for both sides. It is assumed that after arriving the building, people will reach their floor, visit cloakroom for their coats, and then reach their workstations. Unexpectedly, changing the cloakroom's location didn't improve the design at all. In Alternative 2, a door is assigned to the core, to provide an east-west circulation between the workstations and the core. As seen in Table 2, the min. distance and total time (route) is the lowest in this alternative, which is best through these alternatives. Alternative 3 is an option where cloakroom is removed, so there is less traffic on the circulation areas. Alternatively, people may use their closets for personal belongings.

In Alternative 4, social desks, which are located on north and south wing, are removed. There is a critic that those desks are blocking the workstations, but the results came out unexpectedly. There are more red zones in Alternative 4 rather than the previous ones. As a final, Alternative 5 is created, social desks are removed and distance between the workstations are widened. With this alternative, the number of people on the floor is also lesser than before.

User density map was observed to reduce virus spread. In the study on alternative plans; the average of the red color value (RGB:R) of the resulting maps was calculated. After this color channel calculation, improvements have been made to alternative floor plans with high-density red color zones (Table 3).

As a result of simulated alternative plans; we can observe that the least density occurs in the 5th plan alternative.

Table 2. Results of alternative plans on distance, time and speed on 12th and 13th floors (385 agents)

	Total distance (m.)	Total Time (sec.)	Average speed (m./sec.)
Initial Design	33	45.70	0,76
Alternative 1	36.85	47.94	0,77
Alternative 2	31.52	41.03	0,78
Alternative 3	32.68	44.55	0,76
Alternative 4	32.36	44.65	0,76
Alternative 5	32.89	44.76	0,76

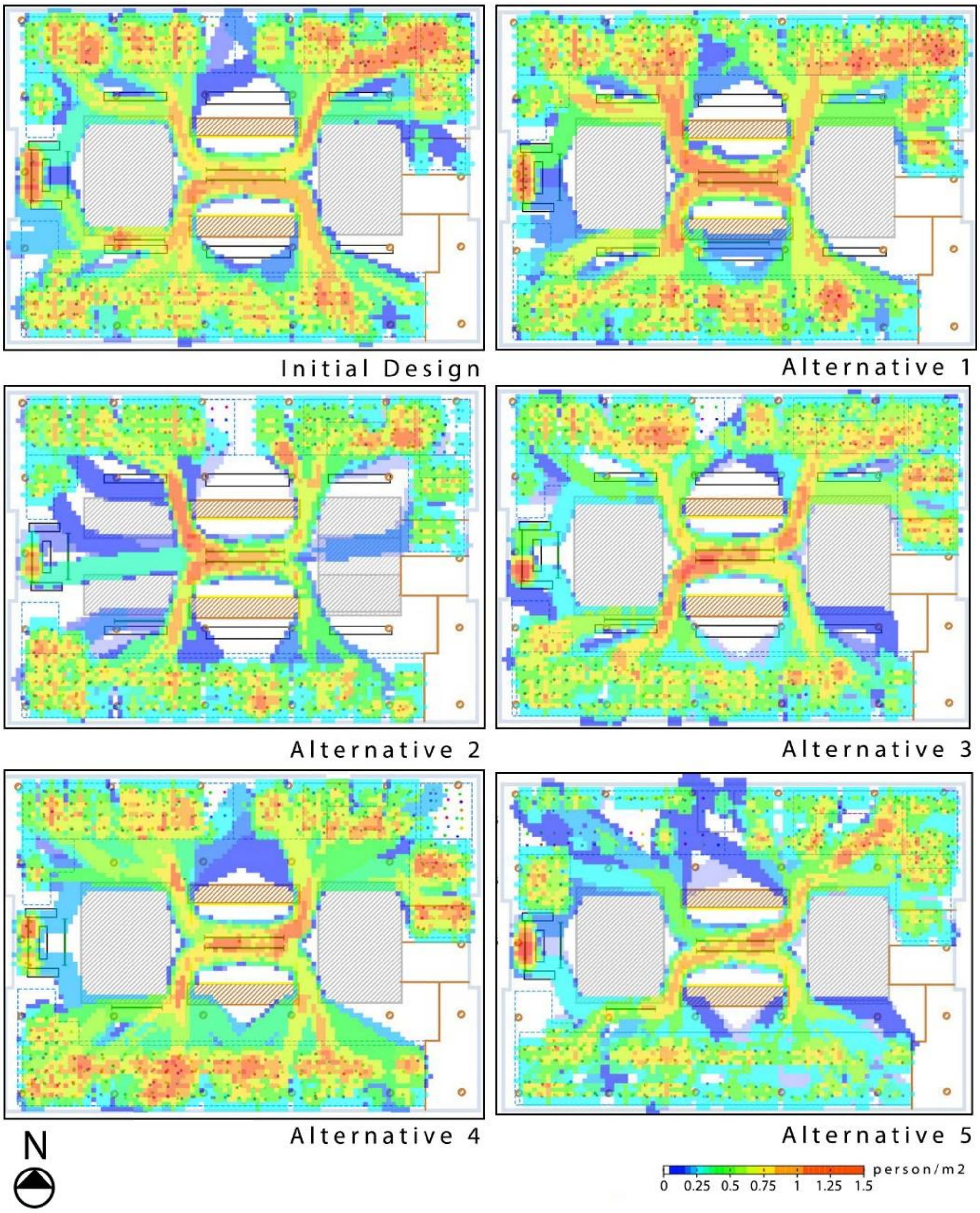

Figure 5. Simulation results of the alternative interior designs (13th floor)

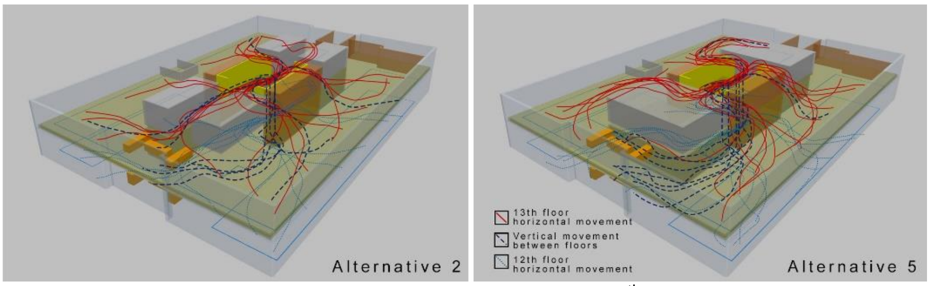

Figure 6. Movement Simulations of Alternative 2 and 5: 13th floor horizontal movement (red continuous line), Vertical movement between floors (dark blue dashed line), 12th floor horizontal movement (light blue dotted line)

Table 3. Color space and channel statistics of the simulations (RGB:R) for the user density analysis

	avg	med	min	max
Initial Design	191	212	82	254
Alternative 1	190	211	74	254
Alternative 2	183	191	82	254
Alternative 3	186	198	81	254
Alternative 4	187	206	82	254
Alternative 5	177	177	83	254

5 Discussion

This simulation enables experimentation on a valid digital representation of a system. It is essential to think about new means of public spaces and working habits after Covid'19. After feeding the model data and receiving the simulation results, the proposed design can be improved wherever the high density becomes a problem. The results showed that simulating user movement in a high-rise office building and changing design decisions will optimize building traffic and improve for a healthier indoor space. This study suggests that office buildings' user movement patterns can differ depending on their business relations. The study focuses on the analysis and verification of modeling of user behavior patterns in office buildings due to user movement data.

This study developed a framework to model and simulate user behavior in office buildings to improve interior design decisions with designers using predefined parameters like employee scheduling, working area location, and user speed. Preventing the spread of the Covid'19 virus and examining architectural spaces with a density map in advance allows solutions to be produced.

Several decision-making processes, such as path change behaviors when simulation continues, require improvements in the study.

In a future study, the whole building will be simulated with all the users. Also, it will be possible to analyze post-occupancy evaluations after the users move into the office building (2023 April) and start working there. It is also suggested that group events at the ground level, such as meetings and organizations, can be analyzed similarly once sufficient data has been collected and analyzed.

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