Redesigning the working space for social distancing: Modelling the movement in an open-plan office

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Abstract

The global pandemic has reshaped the use of working space dramatically, mainly due to the implementation of the working from home policy and indoor social distancing requirements. This calls for the rethinking of the current office design approaches and the proposal of specific design strategies to provide a safer and healthier environment for employees to return to their offices. Also, the demand for enhancing office design to accommodate special and rare events like the pandemic is identified. More resilient and flexible office designs are needed for the post-pandemic era. This study aims to provide an insight into the human movement in the open-plan office setting by simulating the movement using agent-based modelling. Normal scenario and special scenarios with social distancing standards and reduced office capacity are simulated. The simulated scenarios contribute to the development of the new adaptive office design approaches for a safe office resume.

1. Introduction

The COVID-19 pandemic has significantly reshaped the work routine and office experience. The containment measures including lockdown, travel restrictions and social-distancing requirements have reduced the mobility of people, while companies respond to the pandemic challenge with ‘work from home’ policy. Although ‘work from home’ can lead to some improvements in the productivity (1), office still has its irreplaceable role on providing face-to-face communication and building up social connections. The plan for returning to offices is resumed with the delivery of mass vaccination and the release of lockdown.

It is inevitable for people to gather, contact and interact when they go back to offices, which may lead to an increase in the risk of transmission. The non-pharmaceutical interventions like increasing air ventilation and social distancing are proved to be effective (2), while the design of physical environment can help to address the interventions. The effectiveness of the potential ventilation strategies in indoor environment has been discussed in the previous studies (3–6). The questions of how many people can safely access the office, what is the optimal social distance in office, how many people are allowed to use the facilities around the office and how to alter the furniture layout to avoid overcrowding situation need to be addressed. The corresponding office design solutions can contribute to reducing the concentration of people thus reducing the potential of virus spreading. The understanding of how people use and move around the office space is expected to contribute to the decision making on the office reopening plans. The simulation modelling approach can help to model the different scenarios with various intervention strategies like layout changing, social distancing and population limitations. An optimum strategy can be found through this process to ensure a safe resumption.

This study is going to investigate the application of social distancing strategy in the office. It models the movement of people in an office environment with agent-based pedestrian simulation tool and examines the scenarios with various social distancing requirements and limitations on the populations. This investigation is essential for figuring out the appropriate strategy for safe reopening. Also, an enhanced understanding on the movement and potential strategies can contribute to future design. The effectiveness of different layouts and design strategies can be tested with the simulation tools. Furthermore, the agent-based modelling in the normal office setting has the potential to be developed as a comprehensive project, from the observation and collection of behavioural data to establish a model applying specifically to the workspace. This study provides an initial insight for the potential of the investigation.

2. Literature review

The literature review part learns from the existing research on the movement in the office environment and the simulation of pedestrian movement in the built environment. The findings provide a background overview and pave the way for the proposed study.

2.1 Movement in office

A large body of literature has discussed the observation of human activities in the office environment. The behaviours of sitting, standing and walking are widely measured and analysed in the domain of physical health research. The physical activity monitor devices are used to trace the movement and record the sitting and standing time and walking steps, while the questionnaire is applied to collect the self-reported data (7–10). The sedentary behaviour, which indicates a prolonged sitting time of more than 30 minutes (11,12), is considered a threatening to health (13,14). The researchers test different approaches to reduce the sedentary time, such as the use of sit-stand work station (15–17), the renovation of office layout from traditional cells to activity-based type (18) and the seminar, workshop and training sessions. The collected dataset show that the sitting time usually occupies over 60% of the working time (16,19,20), while the largest proportion noted is 93% (21). The recorded standing and walking time is much less than sitting, while the figure varies in different studies, with a range of 10% to 20% for standing (15,22,23) and 7% to 12% for stepping (15,23,24). Spinney *et al.* (25) report the frequency of trips in an office. The trips from the desk per hour is 1.6, and the average number of trips to the restroom and kitchen per hour is 0.38 and 0.96 separately.

The correlation between the movement and spatial configuration is also a major found in the previous research. Carter and Whitehead (26) study the pedestrian circulation in Rail House and notes down 69 activities that can generate movements, such as the visit to mailroom and the use of ground floor entrance. Rassia (27) points out the informal communication for job interaction as a key reason for movement in the office, while the movement is found along the corridors and to landing and reception areas. The movement and interaction hotspots are the individual desks, water coolers and print station (28). The indoor architectural design can have an influence on the occupants' movement pattern by considering the layout carefully (27). The spatial system explains the movement flow in offices effectively, and the results from two case studies show that the metric analysis demonstrates the workplace movement best (29). The movement in offices is driven by the geometric and non-geometric properties and the needs of travelling to attractors. The geometric property refers to the pure spatial configuration measurement, while the non-geometric feature takes the functional configuration (the locations of furniture and functional spaces) into consideration. The travel concentration measurement constructs paths from each seat to attractors of the building entrance, the closest canteen, kitchen and restroom and transforms the paths to the visible zones. This new spatial metric is tested against a large dataset and proved to have some predictive power to the movement activity (30). The correlational analysis of spatial configuration features and movement at micro, meso and macro levels identifies the metrics of visual control, isovist min radial and travel concentration are the most significant measurements to the movement activities. The finding supports the argument of movement mainly taking place in the circulation spaces (31).

2.2 Agent-based movement simulation

The movement simulation has been widely applied in built environment research, because the understanding of how pedestrians move around urban spaces or buildings can play a significant role in assisting the planning and design. The microscopic models like cellular automata, social force and agent-based models are created for the movement simulation (32,33). The agent-based model has a unique feature of involving variability and randomness which leads the system to unknown limits (34,35). Schelhorn *et al.* (36) propose the agent-based STREETS model to look at the pedestrian activities in urban districts by integrating the socioeconomic and behavioural characteristics of agents and the physical environment datasets in the GIS system. The geometric agent-based pedestrian simulation PEDFLOW for the microscope environment is addressed in the work of Kerridge, Hine and Wigan (37). PEDFLOW is a complement work to the STREETS model with a higher level network and decision structure.

The recent two decades have witnessed the emergence of agent-based crowd simulations for different cases and scenarios. A classification framework categorises the type of modelling by environment and behaviour. The type of environment includes small-scale enclosed spaces, large-scale enclosed spaces, mixed-mode, open space and hybrid, while the behaviour categories are purposeful and familiar, purposeful and unfamiliar, purposeless, evacuation, forced-waiting and temporal constraints (38). Shaaban and Abdelwarith (32) explore the pedestrian behaviour when crossing a road, while different pedestrian attributes, like gender, age, clothing, are considered in the investigation. The human and social behaviour in emergency evacuations is demonstrated in works (39–41). Rassia and Siettos (42) introduce the molecular dynamics approach to model the evacuation in office buildings. The simulations at a larger scale or mix-mode environment, like the railway station (43), metro station (44) and outdoor recreation spaces (45).

For the post-pandemic world, simulation tools could assist the decision making by performing possible scenarios of human activities. The importance of simulating the risks and scenarios is also highlighted by the insight from Arup. The Space Explorer tool is introduced as a service to understand people's movement and risk for returning to workspaces (46). The office behaviours and movements are different from the normal crowd movements on streets or around public spaces, as the office is a semi-public environment that involves more complex functions and activities and a longer staying time. While sitting accounts for the majority of working time, relatively less time is spent on standing and walking. Many of the movements around office are generated by the visits to the attractors like printers, restroom and meeting room. The employees have various levels of interactions like chatting, visiting and meeting. According to the classification framework of agent-based pedestrian models by Ronald, Sterling and Kirley (38), the model for the office environment is classified as the small-scale enclosed spaces modelling with purposeful and familiar behaviours. This combination remains a gap in the field. Therefore, there is a need for an integrated tool to model the movement specifically for the working environment as an aid to the post-pandemic office design.

3. Method

This section introduces the data and method used in the movement simulation. Figure 1 illustrates the step-by-step flow chart of this study.

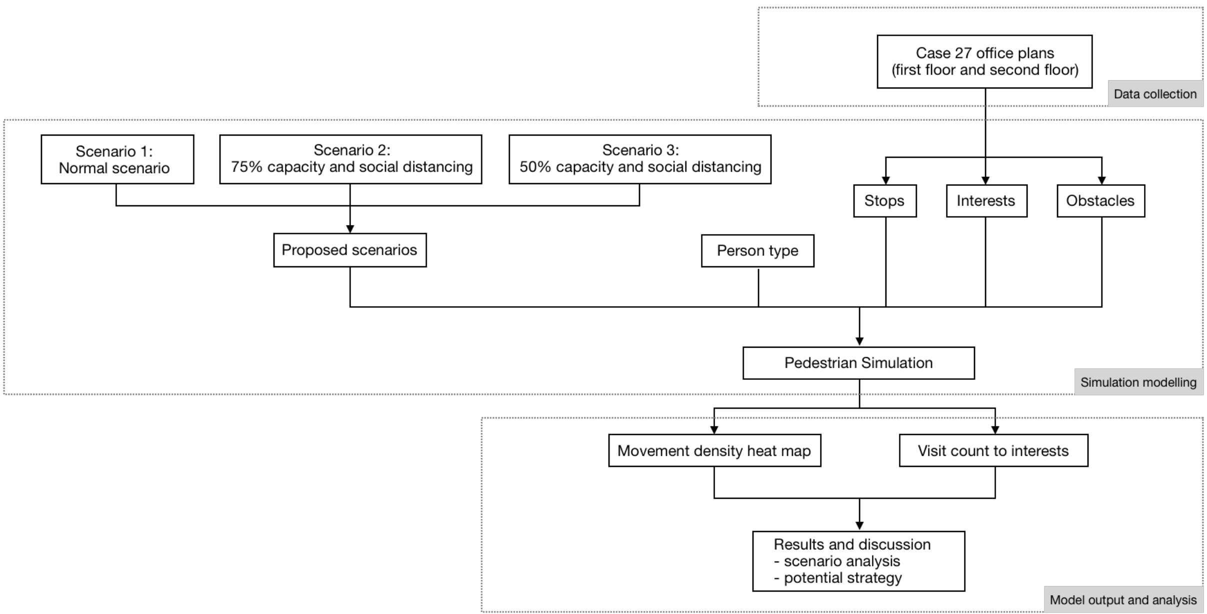

Figure 1 – Steps of the study

3.1 Data collection

The office plans applied in the study are extracted from the collection of plans in Koutsolampros's work (31). The plan comes from the UK office dataset collected by SpaceLab, while a set of predictive analysis on the spatial configuration and the activities of movement and interaction is performed in the previous works (30,47,48). The first and second floors of Case 27 are selected for the analysis considering the availability of relevant information (shown in Figure 2). Except for the floor plan, the function distribution information is also extracted and illustrated (shown in Figure 3). There are a total of 180 desks on the first floor and 174 desks on the second floor with an open office plan. Therefore, the assumptions on the maximum capacity of the offices are 180 and 174 respectively. Both of the floors feature a dense seating plan, classified as dense workspace floors (31). The floor entry and exit are the staircase and three lifts on the corridor. The first floor has four meeting rooms and one alternative working space. The second floor has five meeting rooms and two alternative working areas. There is a restroom and a tea point with seats on each floor and facilities like printers and lockers locating around the floor. The slight differences in the layouts of the two floors make their simulation results comparable.

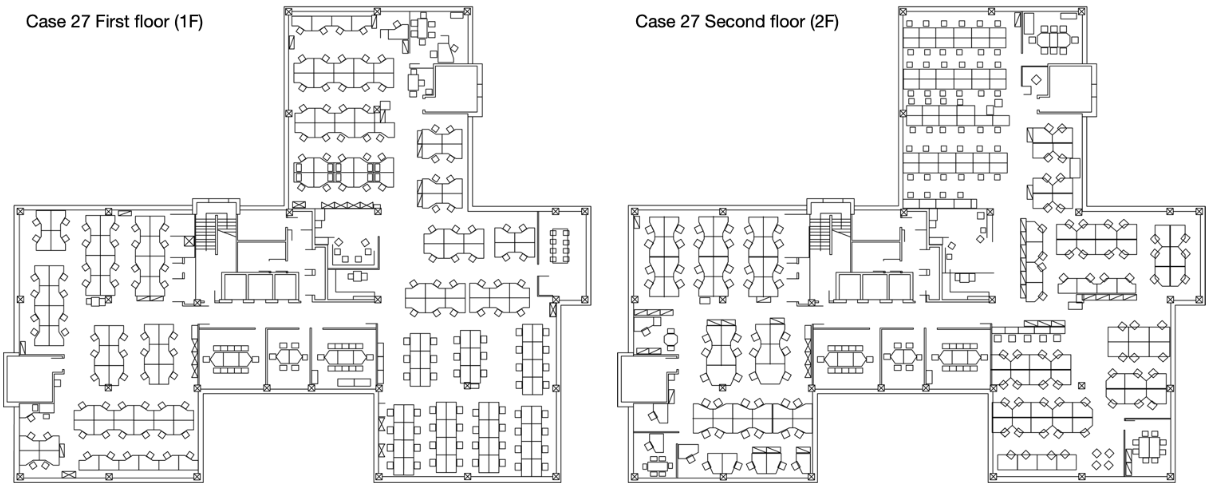

Figure 2 – Floor plan, Case 27 First floor (1F) and Second floor (2F) (adapted from ref. (31))

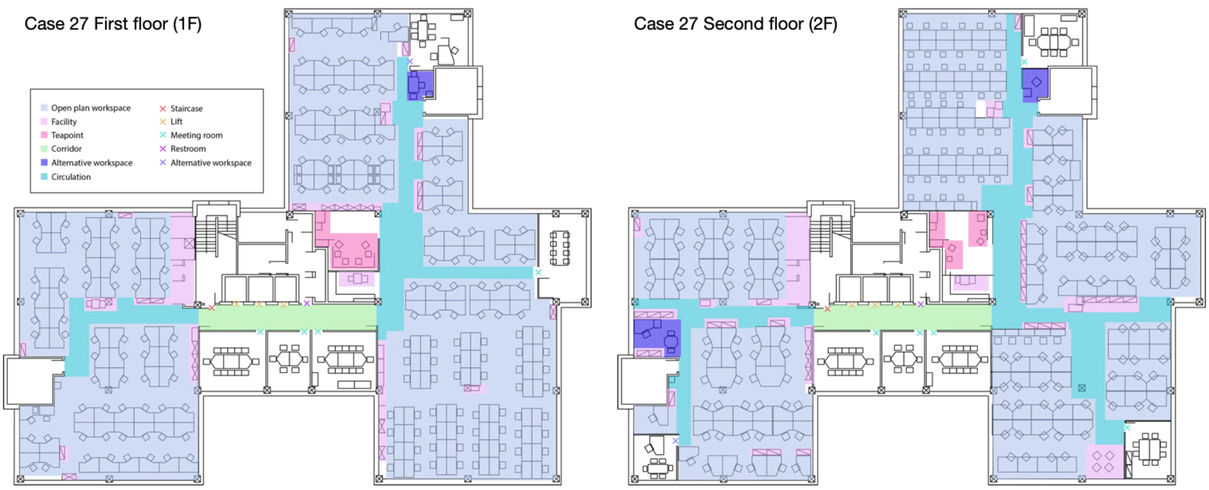

Figure 3 – Floor plan with functions, Case 27 First floor (1F) and Second floor (2F) (adapted from ref. (31))

3.2 Pedestrian simulation setting

The pedestrian simulation plug-in PedSim Pro working under Grasshopper in Rhino is applied to simulate the movement in the open-plan office (49). It is an agent-based simulation tool based on a particle spring system with agents driven by various forces like repulsion and attraction forces. This tool is selected because it is easy to access and allows users to run and design their own scenarios. Its predecessor PedSim is the most popular pedestrian simulation tool in Grasshopper, while PedSim Pro has more features with greater modelling flexibility. The simulation is run on a 3.1GHz Intel Core i7 computer with Rhino 6 and PedSim Pro 1.1.1.

The major components in the simulation modelling are stops, interests, obstacles, person templates and the engine. Stops and interests are the location points on the plan that agents can visit. Stops are the planned targets on the route, including a start, a destination and multiple other visits. The movement route of the agent is defined by the planned stops. Interests are the unplanned stops, as they are visible and accessible. The interest and stop can be set as a room or a stand. The agents who visit a room disappear from the map, while those who visit a stand still remain on the plan and interact with the other agents. Obstacles can be either opaque or transparent, and the setting of obstacles influences the decision of routes. The person template defines the type of agents with different combination of stops and interests. The engine is the essential component that integrates all the stops, interests, obstacles and person templates.

In the simulation, a full circulation from the entry to the desk to the exit is built for each agent. The entry and exit are the staircase and lifts. Each staircase or lift can be either starting point or destination. The planned stop is the desks around the office, and the desks are grouped into four sets according to their zone. The restroom, meeting rooms and an alternative working space are set as interest with the room feature, while the facilities, tea point and an open-plan alternative workspace are assigned as the interest with the stand feature. Each agent can visit a maximum of five interests on their designated route.

Object	**Type of program**	**Stand or Room**	**Number of objects (on each floor)**	**Visiting Time (Unit: s)**	**Capacity (For each program)**
Lift	Stop	Room	3	-	10
Staircase	Stop	Room	1	-	80
Desk	Stop	Stand	4 groups 180 (1F), 174 (2F)	30	1
Meeting room	Interest	Room	4 (1F), 5 (2F)	20	6-12
Restroom	Interest	Room	1	3	6
Alternative workspace	Interest	Room and stand	2 (1F), 3 (2F)	30	3-6
Teapoint	Interest	Stand	8	2-10	1
Facilities	Interest	Stand	31 (1F), 44 (2F)	2	1-2

Table 1 – Model setting in PedSim Pro

Table 1 shows the setting of stops in the PedSim Pro model. The default fixed unit setting is meter (unit: m) for distance and second (unit: s) for time. Due to the limitation of the computing power, the time frame in simulation is scaled down. In the model, 1 second corresponds to 1 minute of real-world time. To get a representative result with the limited computational power, the simulation is run for 90 seconds for each scenario. The profile of the agent, including body radius, mass and speed, follows the default setting in the plug-in, and the vision is set as 'panorama'. There are 16 different combinations of 'entry-desk-exit' route (two entry and exit options of lift or staircase and four groups of seats), thus a total of 16 agent templates are created in modelling. An agent generates from the entry points in every two seconds, and the maximum capacity of the lifts is 10 for each lift. The visit time to working desks is about 30 seconds, which indicates a sedentary time of 30 minutes. Each desk can hold only 1 person. The visit time to the meeting room is set at 20 seconds, and the capacity of the meeting room varies with the size, from 6 people to 12 people. For the tea point, restroom and facilities, the staying time ranges from 3 seconds to 15 seconds and the capacity differs case by case.

3.3 Proposed scenarios

	Total population allowed in the office	**Social distancing (2m)**	**Interest capacity**	**Seating rule**
Scenario 1	Full capacity	No	Normal	No
Scenario 2	3/4 (75%) of full capacity	Yes	Half	No
Scenario 3	1/2 (50%) of full capacity	Yes	Half	Yes

Table 2 – Scenario settings

Three basic scenarios with different virus containment strategies are proposed for simulation (summarised in Table 2). Scenario 1 is the normal scenario with the full capacity. The population presented in the office is 180 on the first floor and 174 on the second floor. Scenario 2 simulates the situation with a reduced number of people and a social distance of 2 meters. Only 75 per cent of the full population can access the office, while the number of people allowed in the meeting rooms, lifts and alternative working spaces is reduced to half of the original capacity. Only one agent can use one facility every time. In scenario 3, half of the population is allowed in the office. The social distancing requirement and the capacity limitations on the facilities and functional rooms are the same as the scenario 2 settings. Additionally, the gap between seats is placed. Only half of the desks are accessible (shown in Figure 4). The snapshots for each scenario are taken, showing the position of agents. All scenarios are run for the first floor, while only the normal scenario is conducted for the second floor. Figure 5 presents the series of snapshots at 30, 60 and 90 seconds for scenario 1 on the first floor, while Figure 6 illustrates the snapshots for all simulated scenarios at the time of 60 seconds.

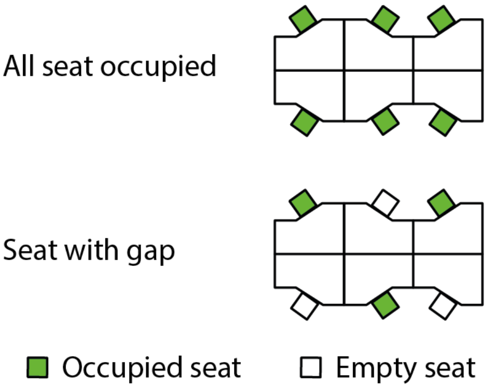

Figure 4 – Illustration of the seat gap

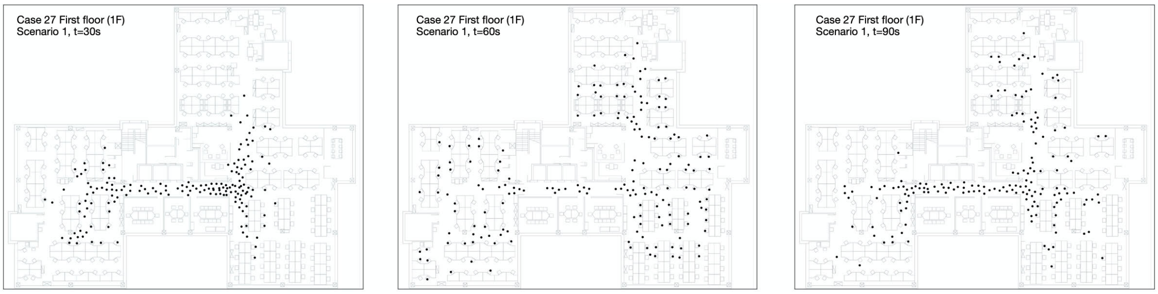

Figure 5 – Scenario snapshots for Case 27, First floor, Scenario 1 (t=30s, 60s, 90s)

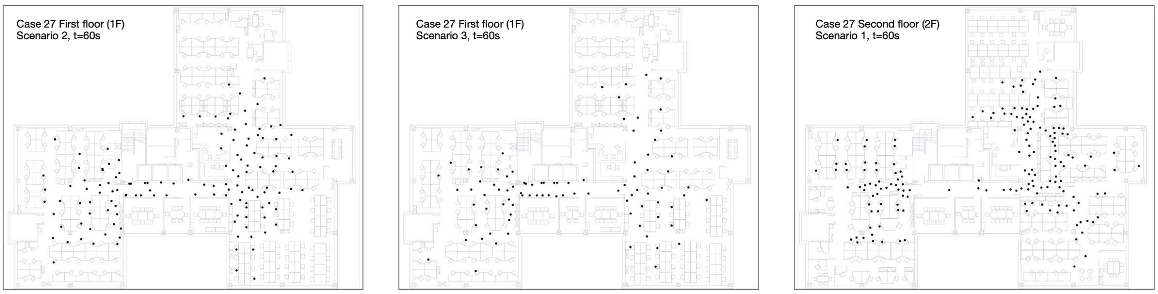

Figure 6 – Scenario snapshots for Case 27, First floor, Scenario 2, Scenario 3; Second floor Scenario 1 (t=60)

The data generated from the model is visualised in the format of heat maps, which shows the movement density around the space. Following the previous analysis (31), the lattice grid with a cell size of 45 by 45 centimetres is used. The number of visits to each cell is counted and presented in the heatmap. The number of visits to the interests is counted to represent their attractiveness.

4. Result and Discussion

4.1 Simulation results

Figure 7 presents the groups of movement density heat maps, and Figure 8 shows the visit count to each interest. Generally, the highest density occurs around the corridor. The visiting density decreases as the distance from the lift and staircases increases. The facilities and desks located far from the corridor have the least visit counts. The tea point is less visited, which could be explained by its poorly visible location. The meeting room and restroom along the corridor are the most visited hotspots, while the visit count to the meeting rooms in the distant area is much less. The facilities around the circulation area also cause some density concentration.

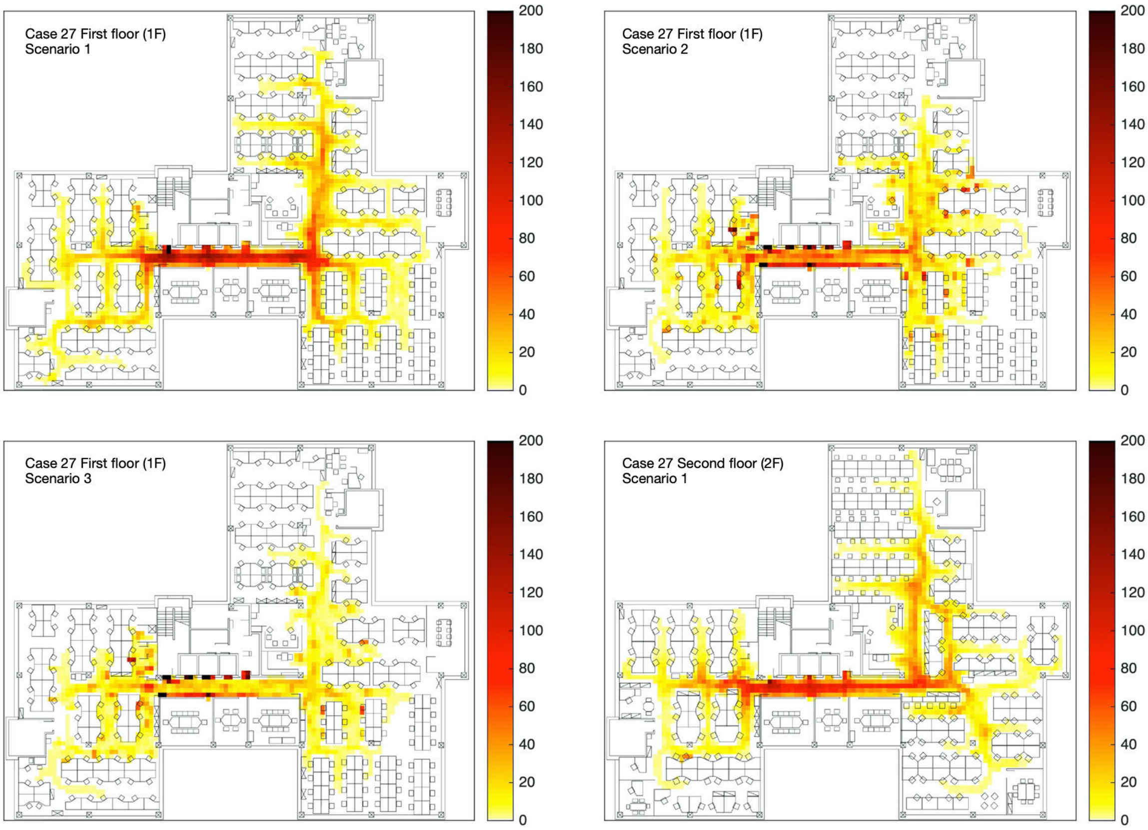

Figure 7 – Heat map

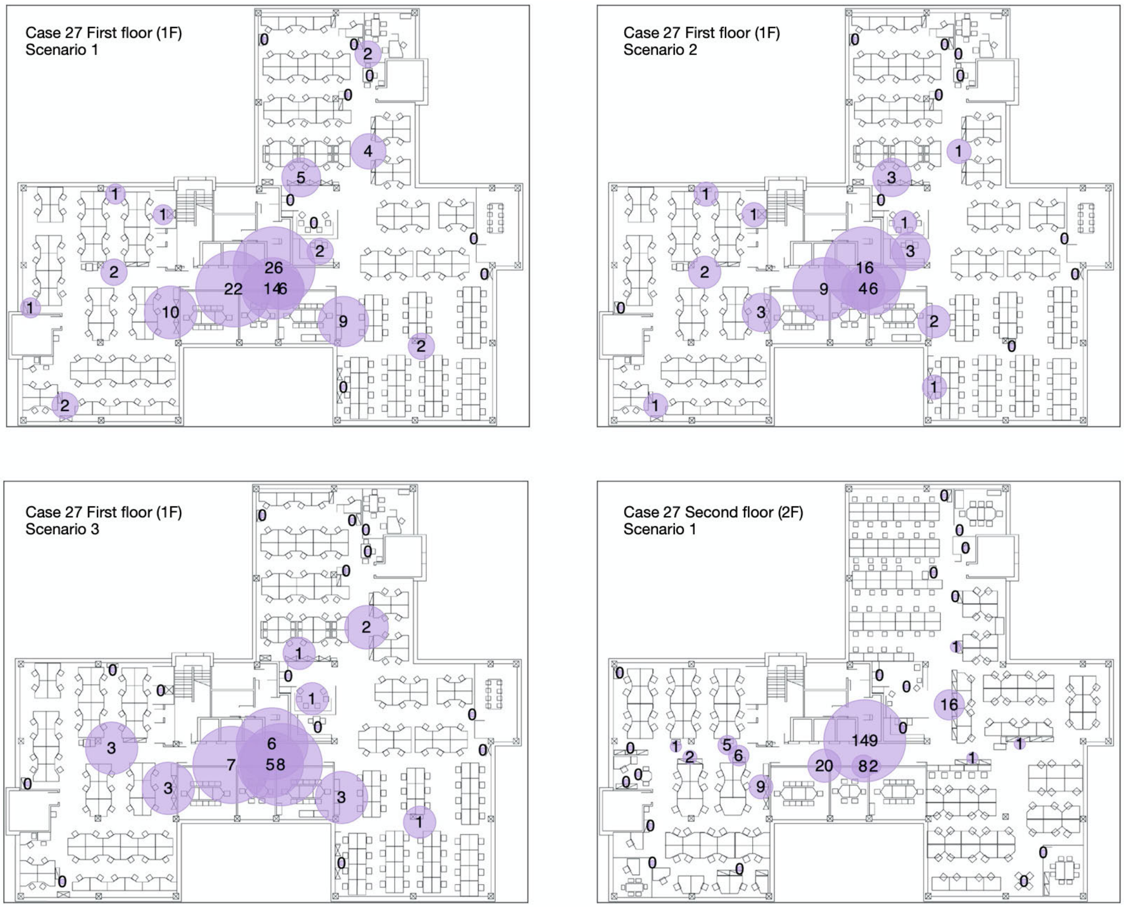

Figure 8 – Visit count of interests

The reduction on the number of occupants in the office has effectively reduced the movement density and the concentration around the interests. The movement area contracts as the number of agents reduces, as the agents do not travel further to reach the desks at the distant corners. In scenario 3, the overcrowding situation still occurs at the entry and exit points and the restroom, while the movement density along the corridor decreases significantly. The impact of social distancing and the seat gap strategies is not apparent on the heatmap. The effectiveness of social distancing measurement is demonstrated by the difference in the use of corridor. In scenario 1 of the first floor, the flow concentrates in the middle of the corridor, while the highest density occurs at the two sides of the corridor near the wall in scenario 2 and 3. The movement flows are separated to maintain the social distance. A noticeable increasing in the distance between agents are shown on the snapshots (Figure 6).

The normal scenario is run for both the first and second floor, while there are some differences in the layout. The main distinctions in the layout occur on the right side of the plan. The upper right quadrant on the second floor has a denser seating arrangement comparing to the first floor. However, there is no significant variation found in the movement around the area. The set of facilities locating along the circulation area opposite to the tea point are visited 16 times, but those interest points do not lead to extra concentration comparing to the same location on the first floor. As the entry and exit points, the restroom, the corridor and the circulation remain in the same location, the general movement flow in both floors looks similar.

The results echo some of the findings from spatial configuration analysis (shown in Figure 9). The three most important metrics are visual control and isovist min radial based on the accessible areas and the in-floor travel concentration (31). Visual control compares the space visible from a cell to the other directly visible cells. Isovist min radial measures the distance from the isovist origin to the nearest obstacle. Travel concentration evaluates the effect of attractors. It is not surprising to see the corridor become the movement hotspot in the plan considering the relatively high indoor travel concentration and isovist min radial value shown in the previous analysis. The high values of the spatial structure metrics are also found around the circulation area outside the tea point, while the area features a relatively dense movement as well.

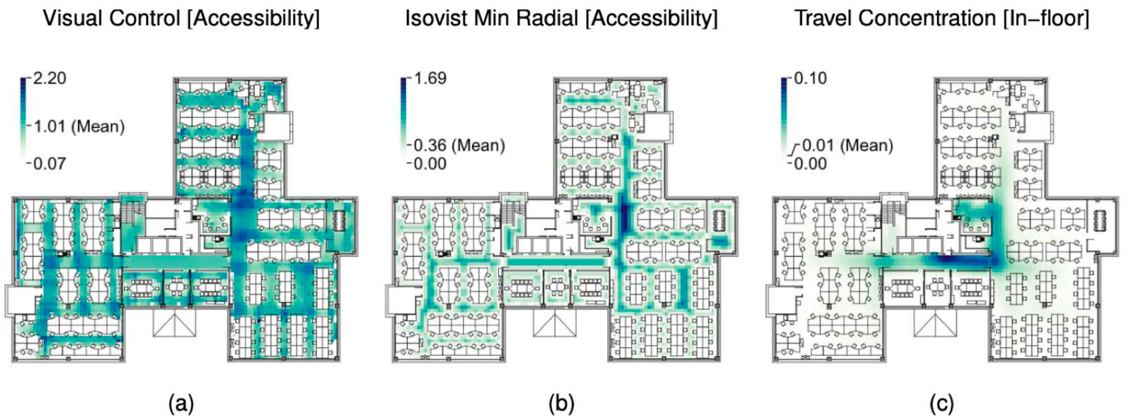

Figure 9 –The three most important spatial configuration metrics to movement, Case 27 First Floor (extracted from ref. (31)**)**

4.2 Potential strategies

In addition to the containment strategies of introducing social distancing, limiting capacity and reducing crowding, the design strategies can be applied to the office space including changing the layout, setting up the one-way system and adding barriers between seats. Also, the 'Working safely during coronavirus' guideline provides a series of suggestions, such as carrying out risk assessments, arranging the workspace to keep people apart, using back-to-back or side-to-side seating, increasing the frequency and restricting the access to different areas (50). The simulation results support the application of social distancing and capacity limitation, while the findings also lead to further reflections on the design of the space.

In the floor plans examined in this study, a high concentration of movement is found in the corridor area, mainly due to the location of staircase and lifts. At the same time, employees need to pass the corridor to get access to the meeting rooms and restroom, which adds to the crowding density. To reduce the high traffic around the corridor, diverting the movement flow in the corridor is essential. The entry and exit points could be separated, which indicates a greater distance between the staircase and lifts. The meeting rooms can be re-layout from their current location to the less accessible areas. This measure could alleviate the travel concentration around the corridor and discourage employees to visit the meeting rooms, as meeting rooms are small and enclosed areas with a higher risk of spreading. Some of the facilities can be relocated from the locations around the circulation area to less accessible spaces.

5. Conclusion and limitations

In conclusion, this study provides an initial insight into the movement simulation in the workspace. The literature review indicates that there is a need for more targeted simulation tools for different scales, scenarios and environments. The study demonstrates how the movement simulation in the office environment could potentially support the decision making in the office reopening in the post-pandemic era. While the government guideline sets the general approaches, the movement simulation tool helps to provide more detailed analysis and solutions by looking into a specific case and modelling case-specific scenarios. Comparing to the existing agent-based modelling research which focuses more on the design of models, this study explores the potential of applying the simulation results to real cases. In this case, the results highlight that the corridor is the high movement density area. There is a need for some specific considerations on reducing the movement concentration around the corridor.

There are several limitations of this study, which influence the accuracy of the simulation. Firstly, the model inputs are designed based on the secondary sources and assumptions with a lack of primary data involved. The generalised and simplified movement pattern used for simulation is relatively simple, and it could not accurately reflect the complex situation in the real office environment. Secondly, the tool used in this simulation is designed for the understanding of general movement instead of for office-specific scenarios. This plug-in is unable to simulate the vertical movement between different floors, though the two plans used in this study are from the same case. Only the movement within floor is modelled. The personal templates allow some degree of diversity and flexibility in the agent setting, the agents still tend to be homogenised in the model. Thirdly, the agent-based simulation results involve randomness, which indicates that the results for every single simulation could have slight differences. The future investigation can be coupled with environment modelling, especially the simulation of air ventilation in the office space, to understand the behaviour and assess the risk of returning to the offices.

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