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A Simulation and Visualization Model for Occupants' Movements in Instructional Buildings

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ABSTRACT

Building renovation is one effective method to redefine the use of the building and improve its efficiency. However, architects renovate the building based on their personal subjective perception of how the occupants use the building instead of systematical analysis of their use behaviors. This research develops a simulation and visualization system based on an activity model and a pedestrian movement model. The system simulates how occupants move and use the spaces of a building given the defined spaces of the building and the associated probabilistic activities of occupants. The Monte-Carlo-based simulation results are displayed with animation and allowed users to perform a variety of what-if analyses regarding space layout and movement circulation. A case is also described in this paper to demonstrate the use of the system.

Keywords: simulation, activity-based model, pedestrian movement model.
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1 INTRODUCTION

Practitioners and researchers have paid much attention to the maintenance of a constructed building facilities or civil infrastructure in the past decade. Some dealt with the detection of the structure failure [14] and the assessment of surface quality [1]. Others discussed the complex constraints imposed by the owner to ensure the normal operation of the remaining portion of the building when reconstruction activities were underway [9]. Moreover, most research has focused on the estimation of the maintenance budgets [12]. Nonetheless, the above-mentioned aims to regain the built environment to its original state as much as possible for prolonging the usage life. Such research rarely concerns improving or upgrading the original-designed functional performance (e.g., occupants' comfort and usage efficiency) of the built environment to meet the needs of current occupants when making maintenance decisions.

Building renovation is one effective method to redefine the use of the building and improve its efficiency. In architectural practice, it has been realized that there is a considerable gap in the communication between architects and occupants which sometimes brings about the failure in building renovation. Architects renovate the building based on their personal subjective perception of how the occupants use the building instead of systematical analysis of their use behaviors. In particular, there are hundreds of undergraduates, graduate students and professors perform some activities in an instructional building, primarily including teaching, research, meetings, and office work. The building renovation mostly depended on an architect and a head of instructional administrator that is easy to ignore difference types of occupants of usage behavior. On the other hand, performing actual simulation experiments by manual observation or automated record is an extremely difficult task. It has time constraint on occupants and takes extremely high experiments cost. Therefore, several new methodologies will be developed and utilized in the renovation of existing building into intelligent one. These include methodologies for tracking current usage of built environment, data-mining usage patterns, simulating built environment, animating usage data, decision-supported reconfiguration, etc.

Based on the activity-based model and pedestrian movement model, the aim of the research is to develop a simulation system for occupants' movements in an instructional building. The system allows users to classify occupants (e.g., freshman boys), define the movement of each type of occupants (e.g., weekly classes, the probability distribution of being late or early for the scheduled class), and read building floor plans and functions of each space unit. The system randomly generates occupants' movement data based on the Monte Carlo simulation and the given probability distributions. The output includes a report that shows the detailed information (e.g., walking distance, the number of occupants per room, the number of people of the flowed path) about how occupants move among space units within the simulation time. The animated simulation result would also be viewed so that users might rearrange the space layout and perform what-if analysis.

To achieve our goal, the paper is conducted through following processes. Section 2 describes a process model for activity scheduling simulation in instructional buildings based on activity-based model. Section 3 introduces a process model for occupants' movement simulation in instructional buildings based on pedestrian movement model. After that, the system architecture of occupants' movement simulation and visualization is presented in the 4th section. Meanwhile, a case is illustrated in this paper to demonstrate the use of the system in the 5th section.

2 ACTIVITY-BASED MODEL

According to activity-based approach, travel demand is derived from activity participation. Activity participation involves generation, spatial choice, and scheduling components. Activity and travel behavior are delimited by temporal and spatial constraints. Therefore, linkages exist between activities, locations, times and individuals. [11]. Arentze (2000) proposed a learning-based transportation oriented simulation system is conducted when, where, for how long, with whom, and the transport mode involved designed as a Rule-based model [2]. Similarly, the research developed activities scheduling simulation model in instructional buildings which was based on Rule-based model.

2.1 Activities Attributes in Instructional Buildings

Doherty (1998) pointed out that occupants tend to schedule their activities in a priority based, rather than time sequential way [5]; for instance, the high priority activities was top scheduled, the low priority activities was scheduled when having available time. In this research, the anticipant activities divided into constrained activities and non-constrained activities in the instructional building which was based on the activities priority of above mentioned. Occupants performed constrained activities containing elective, required, seminar and so on; occupants performed non-constrained activities containing library materials searching, personal research, etc.

In this research, taking a week is a unit of activity schedule in an instructional department. Occupants of main types include undergraduates and graduate students and activities of main content include lessons, research and seminars. The instructional administration department arranged the attributes of constrained activities. Therefore, the constrained activities attributes have not been chosen by occupants' preference. Instead, the non-constrained activities attributes have been chosen freely by occupants' preference besides time and location constraints of the constrained activities. Tab. 1 defined constrained activities and non-constrained activities of attributes and decision makers. The hypothesis of this research was that constrained activities attributes of probability distribution, including activity frequency, start time, duration, locations, and activity time range, have been chosen by instructional administration department except activities attendance, arrival time and leaving time. However, non-constrained activities attributes of probability distribution, including activity frequency, start time, duration, locations, and activity time range, have been chosen by occupants' preference. Namely, constrained activities have much more time and locations restrictions than non-convention activities, despite constrained activities with higher priority in scheduling. The above-mentioned attributes of probability distributions were expressed by common probability distribution functions. In addition, the hypothesis of this research was that attributes of probability distributions were independent each other.

Activities attributes	Constrained activities		non-Constrained activities	
	Attributes	Decision maker	Attributes	Decision maker
Activity frequency of probability distribution	●	Administrator	●	Occupants
Activity start time of probability distribution	●	Administrator	●	Occupants
Activity duration of probability distribution	●	Administrator	●	Occupants
Activity locations of probability distribution	●	Administrator	●	Occupants
Activity time range of start and end weeks	●	Administrator	●	Occupants
Activities attendance of probability value	●	Occupants		
Activity arrival time of probability distribution	●	Occupants		
Activity leaving time of probability distribution	●	Occupants		

Tab. 1: Attributes of constrained activities and non-constrained activities.

2.2 The Process Model for Activity Scheduling Simulation

The process model for activity scheduling simulation is described as the following statements and Fig. 1.

(1) Phase I : Instructional Administration Department of the Constrained Activities Schedule

a. Randomly choose activities list : First, the system randomly chooses activities from instructional administration department of the constrained activities list.

b. Activity time is in the predefined simulation weeks of start and end range : Second, check activity time. If it is not in the predefined simulation weeks of start and end range, the system will eliminate this activity and come back step a. to choose other activities; instead, if it is in the predefined simulation weeks range, the system will perform next step.

c. Generate activity attributes : If activity time is in the predefined simulation weeks of start and end range, the system will generate this constrained activity attributes, containing activity frequency, activity start time, activity duration and activity locations.

d. Activity attributes conflict with other activities attributes : Moreover, check to see if the occupant of this activity simultaneously performs other activities and this activity location conflicts with other activities locations. If this activity attributes are not conflict with other attributes, the system will confirm it and make arrangements for next activity; if this activity attributes are conflict with other attributes, the system will re-arrange their attributes and check them again. The system will reduce the activity frequency if this activity attributes are still conflict with other attributes after many times re-arranging.

e. All the constrained activities list are done with scheduling simulation : Simulation process repeats step a., step b., step c. and step d. until instructional administration department of the constrained activities list have been scheduled or eliminated to stop. Finally, this part simulation output data are the constrained activities attributes.

(2) Phase II : Occupants of the Constrained Activities Schedule

a. Randomly choose activities list : First, the system randomly chooses activities from occupants of the constrained activities list.

b. Generate occupants preferences of activity attributes : Occupants' activity attendance probability, activity arrival time and activity leaving time depended on given the defined probability distribution. The system performs sampling to generate occupants' preferences of above activity attributes, and integrates phase I of simulation results into occupants' activity pattern.

c. All the constrained activities list are done with scheduling simulation : Simulation process repeats step a. and step b. until occupants of the constrained activities list have been scheduled and generated occupants' activity pattern to stop.

(3) Phase III : Occupants of the non-Constrained Activities Schedule

a. Randomly choose activities list : First, the system randomly chooses activities from occupants of the non-constrained activities list.

b. Activity time is in the predefined simulation weeks of start and end range : Second, check activity time. If it is not in the predefined simulation weeks of start and end range, the system will eliminate this activity and come back step a. to choose other activities; instead, if it is in the predefined simulation weeks range, the system will perform next step.

c. Generate occupants preferences of activity attribute : If the activity time is in the predefined simulation weeks of start and end range, the system will generate occupants preferences of non-constrained activity attributes, containing activity frequency, activity start time, activity duration and activity locations.

d. Activity attributes conflict with other activities attributes : Compared with constrained activities, non-constrained activities have low priority to perform scheduling simulation. Hence, the system must search activity start time within available time range. For non-constrained activities of start time, the system will first choose minimum available time range if having much of available time; nevertheless, the system will re-arrange activity start time range, activity duration and re-search available time again if having no available time. The system will reduce the activity frequency if it still has no available time after many times re-arranging.

e. All the non-constrained activities list are done with scheduling simulation : Simulation process repeats step a., step b., step c. and step d. until occupants of the non-constrained activities list have been scheduled or eliminated to stop. Finally, the simulation output data are occupants' activity pattern.

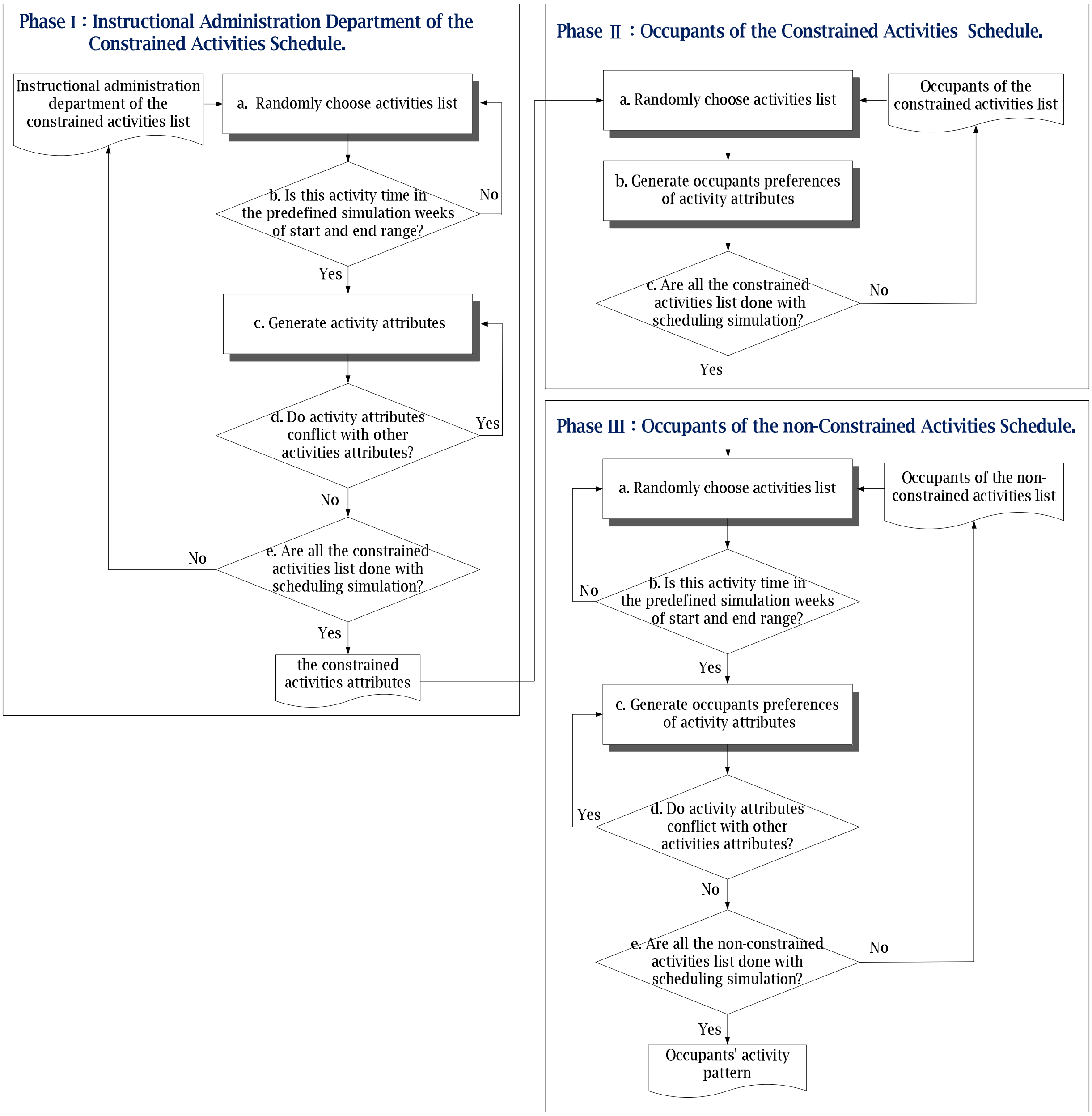

Fig. 1: A Process Model for Activity Scheduling Simulation.

3 PEDESTRIAN MOVEMENT MODEL

Human crowds exhibit highly complex behavior driven by individual decisions of agents with respect to their goals, environmental obstacles, and other nearby agents [13]. We cited Hao's study [8] from cellular automata to develop pedestrian movement model in instructional buildings. The model is defined on a discrete $W \times W$ cell grid in a three-dimensional system, where W is the system size. The size of a cell corresponds to approximately 0.4×0.4 m^2. This is the typical space occupied by a pedestrian in a dense crowd [3]. Each cell can either be empty or occupied by no more than an occupant or obstacle.

The simulation procedure is divided into discrete time steps. In every time step, an occupant can move only one cell in 3×3 field (V_{max}=1). The movement field as the possible choice of position is depicted in Fig. 2(a). Occupants choose to wait or move toward one of the eight possible directions according to the corresponding transition payoff, and a 3×3 matrix of transition payoff S_{ij} is constructed to describe the transition payoffs for the occupant to make choices. $S_{0,0}$ indicates the payoff for the pedestrian to wait at the core cell. The other eight S_{ij} indicate the payoffs for the pedestrian to move to the corresponding cells. In addition, it is assumed that every pedestrian will evaluate the payoff of each possible step before making any movement. The transition payoff is computed with four dynamic parameters describing the occupants' judgment on the surrounding conditions while walking, which plays a decisive role in the occupants' actual choice of position in each time step. These four parameters: Direction-parameter, Category-parameter, Forward-parameter, and Environment-parameter determine the transition payoff in such a way that a particle is more likely to move to the cell with a greater value of dynamic parameter. The transition payoff is presented through these four dynamic parameters, and the maximum and minimum values of every parameter are granted 1 and -1, respectively. The pedestrian would choose the cell with the largest value S_{ij} in the matrix of transition payoff as his or her target position (see Eqn. (3.1)). These four parameters and simulation process will be defined in the following subsections.

$$Max\, S_{ij} = P_D D_{ij} + P_C C_{ij} + P_F F_{ij} + P_E E_{ij} \tag{3.1}$$

Where D_{ij} is Direction-parameter, C_{ij} is Category-parameter, F_{ij} is Forward-parameter and E_{ij} is Environment-parameter; the coefficient of Direction-parameter is P_D, the coefficient of Category-parameter is P_C, the coefficient of Forward-parameter is P_F, and the coefficient of Environment-parameter is P_E.

3.1 Dynamic Parameter Definition

In the system, every cell possesses four dynamic parameters: Direction-parameter, Category-parameter, Forward-parameter, and Environment-parameter in the movement field. In detail, Direction-parameter indicates the cell's degree of approximation to the pedestrian destination; Category-parameter describes the proportion of the number of empty cells and pedestrians homogeneous with the subject in his direction of destination in the field around his target position; Forward-parameter describes the proportion of empty cells in the field ahead of his target position; Environment-parameter indicates whether the cells have obstacles. Take the up pedestrian as an example to illustrate the computation of the four dynamic parameters.

(1) **Direction-parameter:** Pedestrians show an aversion to taking detours or moving opposite to the desired walking direction, even if the direct route is crowded [7]. As to the Direction-parameter, the payoff for a pedestrian to make each possible step is the degree of approximation of the target cell to his or her destination. When the up pedestrian moves straightforwardly, he will gain 1 unit of payoff by approaching the destination with every single step. The values of elements of Direction-parameter matrix are defined by Eqn. (3.2) [8]:

$$D_{ij} = \begin{cases} 1 & \text{for the middle cell in the upper row} \\ 0.7 & \text{for the upper - left and upper - right cell in the upper row} \\ 0 & \text{for the cells in the middle row} \\ -0.7 & \text{for the down - left and down - right cell in the bottom row} \\ -1 & \text{for the middle cell in the bottom row} \end{cases} \tag{3.2}$$

Fig. 2(b) shows the Direction-parameter value. In the 3×3 movement field centered with the pedestrian moving upwards, the Direction-parameter value of the middle cell in the upper row in front of the pedestrian is 1; that of the upper-left and upper-right cells in the upper row in front of the pedestrian is 0.7; that of the three cells in the middle row is 0; that of the middle cell in the bottom row behind the pedestrian is -1 and that of down-left and down-right cells in the bottom row behind the pedestrian is -0.7.

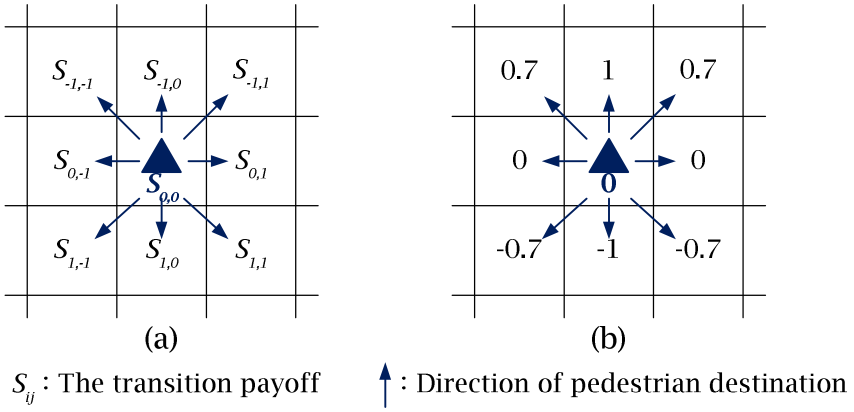

Fig. 2: (a) The allowed choices of action and associated matrix of transition payoffs. (b) A schematic illustration of the payoff of the Direction-parameter gained by an up pedestrian with one step being taken.

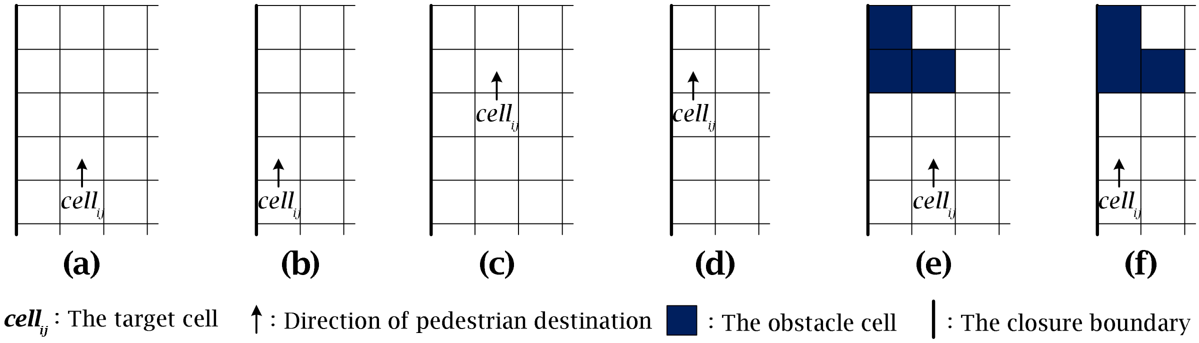

Fig. 3: Dynamic parameters of computation illustration in the vision-conscious field. (a) Forward-parameter with the $Cell_{ij}$ not next to the boundary. (b) Forward-parameter with the $Cell_{ij}$ next to the boundary. (c) Category-parameter with the $Cell_{ij}$ not next to the boundary. (d) Category-parameter with the $Cell_{ij}$ next to the boundary. (e) Environment-parameter with the $Cell_{ij}$ not next to the boundary. (f) Environment-parameter with the $Cell_{ij}$ next to the boundary.

When the values of Category-parameter, Forward-parameter and Environment-parameter are computed, a 3×5 or 2×5 vision-conscious field for the pedestrian is adopted (see Fig. 3).

(2) **Category-parameter:** As it is well known that pedestrians have a tendency to move as a group, there is little interference between pedestrians within the same group. Category-parameter describes the proportion of pedestrians in the direction of destination in the field around the target cell, who are homogeneous with the subject at the core cell in the movement field. While computing the value of the Category-parameter, the empty cells are considered to be the homogeneous cells with the subject at the core cell in the movement field. The greater the number of pedestrians same as the subject is, the greater the Category-parameter value of target cell is. The value of elements of Category-parameter matrix is defined by Eqn. (3.3) [8]:

$$C_{ij} = \begin{cases} \dfrac{S_1 - S_2}{15} & \text{for the target cells which are not next to the closure boundary} \\ \dfrac{S_1 - S_2}{10} & \text{for the target cells which are next to the closure boundary} \end{cases} \quad (3.3)$$

where S_1 is the number of empty cells and pedestrians in the vision-conscious field, who are homogeneous with the subject at the core cell in the movement field and S_2 is the number of pedestrians in the vision-conscious field, who are not in the same destination with the subject at the core cell in the movement field.

(3) **Forward-parameter:** Pedestrians generally choose to move toward the front field containing more empty cells which render more opportunities for pedestrians to choose in the movement toward the destination and jamming can be avoided to the largest extent. Forward-parameter is here presented to reflect the target cell attractiveness to the pedestrians through the number of empty cells in the front field ahead of the target position. The greater the number of empty cells is, the bigger the value of Forward-parameter is. The value of elements of Forward-parameter matrix is defined by Eqn. (3.4) [8]:

$$F_{ij} = \begin{cases} \dfrac{S_1 - S_2}{15} & \text{for the target cells which are not next to the closure boundary} \\ \dfrac{S_1 - S_2}{10} & \text{for the target cells which are next to the closure boundary} \end{cases} \tag{3.4}$$

where S_1 is the number of empty cells and S_2 is the number of occupied cells in the vision-conscious field.

(4) **Environment-parameter:** The pedestrian often feels uncomfortable when walking close to borders of walls, trash cans, construction sites, obstacles, and so on. He must pay more attention to avoid the danger of getting hurt. Therefore, pedestrians keep a certain distance from obstacles [7]. Environment-parameter is indicated to reflect the target cell attractiveness to the pedestrians through the number of no obstacles cells in the front field ahead of the target position. The greater the number of no obstacles cells is, the bigger the value of Environment-parameter is. The value of elements of Environment-parameter matrix is defined by Eqn. (3.5):

$$E_{ij} = \begin{cases} \dfrac{S_1 - S_2}{15} & \text{for the target cells which are not next to the closure boundary} \\ \dfrac{S_1 - S_2}{10} & \text{for the target cells which are next to the closure boundary} \end{cases} \tag{3.5}$$

where S_1 is the number of no obstacles cells and S_2 is the number of obstacles cells in the vision-conscious field.

3.2 The Process Model for Occupants' Movement Simulation

The process model for occupants' movement simulation is described as the following statements and Fig. 4.

a. Generate the movement velocity : First, the system reads occupants' activity pattern and movement direction of the weight coefficient data and then randomly generates movement velocity for each occupant. The system sets pedestrian movement velocity within 1 cell/s to 4 cell/s ranges according to Federal Highway Administration of 1.22 m/s walking speed.

b. Calculate the movement direction : Second, the system takes A* algorithm to calculate the occupants' shortest path from original position to target positions [6]. The occupant then chooses the cell with the largest value S_{ij} in the matrix of transition payoff as his or her target position in every time step. The transition payoffs S_{ij} include Direction-parameter, Forward-parameter, Category-parameter and Environment-parameter.

c. Update the occupants position : Moreover, the system uses random sequential method to update occupant position [10]. If the occupant is in the cell with the largest value S_{ij}, he will stay at the original position and will not move to any other cell. If there have empty cells, the occupant will move to the cell having the largest value S_{ij}; if there have no empty cells, the occupant's moving direction will be compared with the other occupant who has the largest value S_{ij} Based on 50% exchange probability, two occupants will mutually exchange position if they are in the opposite moving direction, and vice versa [4].

d. All occupants are completed movements simulation at each time step : Within a time step, the system randomly selected occupants to perform position update. It stops until all occupants conduct one time movement simulation process. In addition, the next time simulation comes after the last time simulation completed. Simulation process repeats step a., step b. and step c. until over setup time to stop. Finally, the simulation output data are the occupants' movement trajectory.

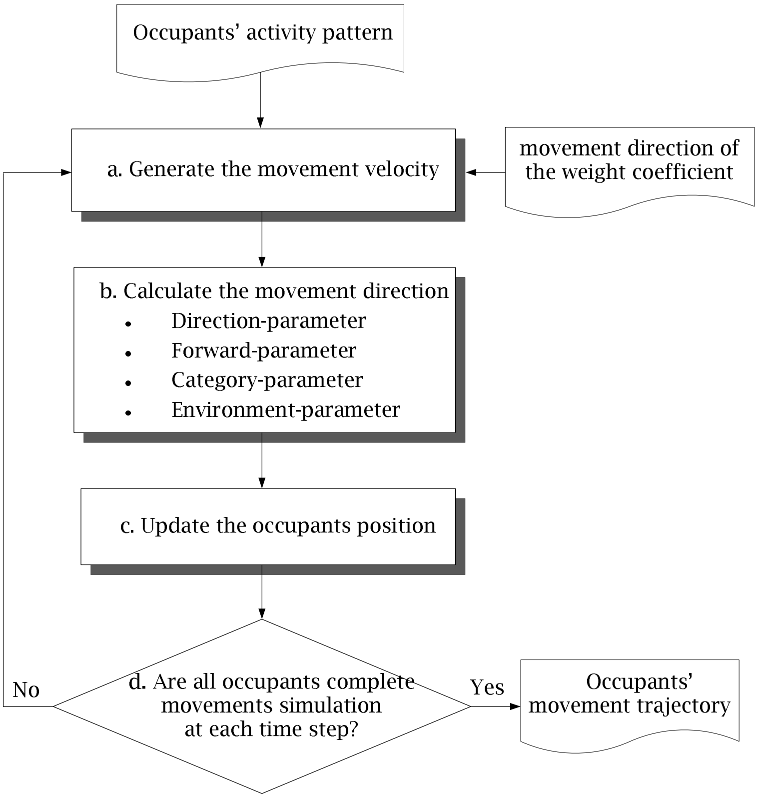

Fig. 4: A Process Model for Occupants' Movement Simulation.

4 A SIMULATION AND VISUALIZATION SYSTEM FOR OCCUPANTS' MOVEMENTS

The system architecture of occupants' movement simulation and visualization is based on the three-tier design, which consists of user-interfaces, application functions, and databases as shown in Fig. 6. The tier 1 is user-interfaces define administration and end-user interfaces. The users can access information through Microsoft Internet Explorer, including multi-attribute of space performance efficiencies, occupants' activity pattern and occupants' movement trajectory animation. Administrators can control and manage this information through web browser as well as a separate server interface. The tier 2 is application functions consists of (1) building data, (2) activity scheduling simulation, (3) occupants' movement simulation, (4) performance evaluation, (5) visualization. The functions were developed by using Microsoft Visual C++ 6.0 and DirectX 7.0. Application functions run under the Windows 2000 sever environment. What follows here are descriptions of each application module.

(1) **Building data**: The module is aimed to develop user's interface to input building floor plans, space layout and other unit layout. According to the above-mentioned input data, the module would judge feasible pathway and search movement routes between two arbitrary space units inside the building; besides, the module output data is as the pedestrian movement simulation basis.

(2) **Activity scheduling simulation**: The module is aimed to develop user's interface to input Instructional administration department of the constrained activities list, occupants of the constrained activities list and the non-constrained activities list. According to the above-mentioned input data and activity scheduling simulation process, the module would randomly generated occupants' activity behavior data, and then performed the activity scheduling simulation. The module output data is the occupants' activity patterns.

(3) **Occupants' movement simulation**: The module is aimed to develop user's interface to input the weight coefficient of movement direction. According to the above-mentioned occupants' activity patterns and occupants' movement simulation process, the module would perform occupants' movement simulation. Besides, the module would record the necessary data during the simulation. One of the module output is the occupants' movement trajectory, that is, the visualization module's input data; the other is the detailed information about how occupants move among space units within the simulation time, that is, the performance evaluation module's input data.

(4) **Performance evaluation**: Based on occupants' movement simulation module, the module is aimed to calculate multi-attribute of space performance efficiencies values to provide administrators to perform a variety of what-if analyses regarding space layout and movement circulation. Moreover, multi-attribute of space performance efficiencies values would be also kept in files as PDF or text.

(5) **Visualization**: To assist users understand the dynamic change with time about how occupants move and use the spaces of a building, the module is aimed to display the occupants' movement trajectory by animation demonstration. The occupants' movement trajectory of 2D and 3D animation are demonstrated in Fig. 5. In addition, the module would express the performance evaluation module of statistic information by means of visual diagrams (such as blocks of color charts) in order to help users further comprehending.

The tier 3 is databases were developed by using Microsoft SQL Sever 2000. This system includes three types of databases, such as building database, activity scheduling database, occupants' movement database. The building database, managed building environment layout pattern, includes walls, doors, windows, stairs, columns, etc. The database enables users to reuse them to construct occupants' movement simulation environment systematically. The activity scheduling database customizes the schedules which were based on different types of activities and occupants. The occupants' movement database gets occupants' movement trajectories from activity scheduling database.

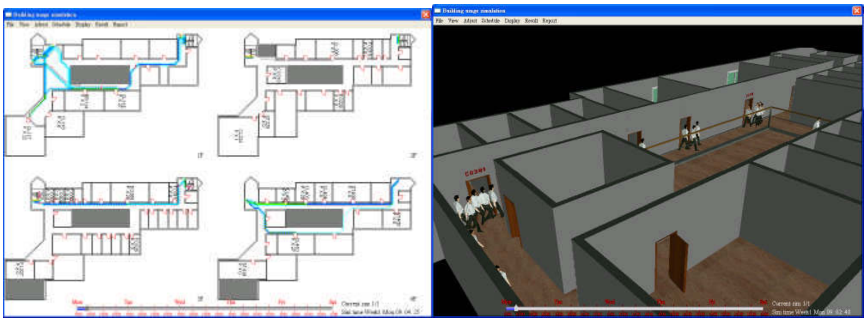

Fig. 5: Occupants' movement trajectory—(a) 2D animation, (b) 3D animation.

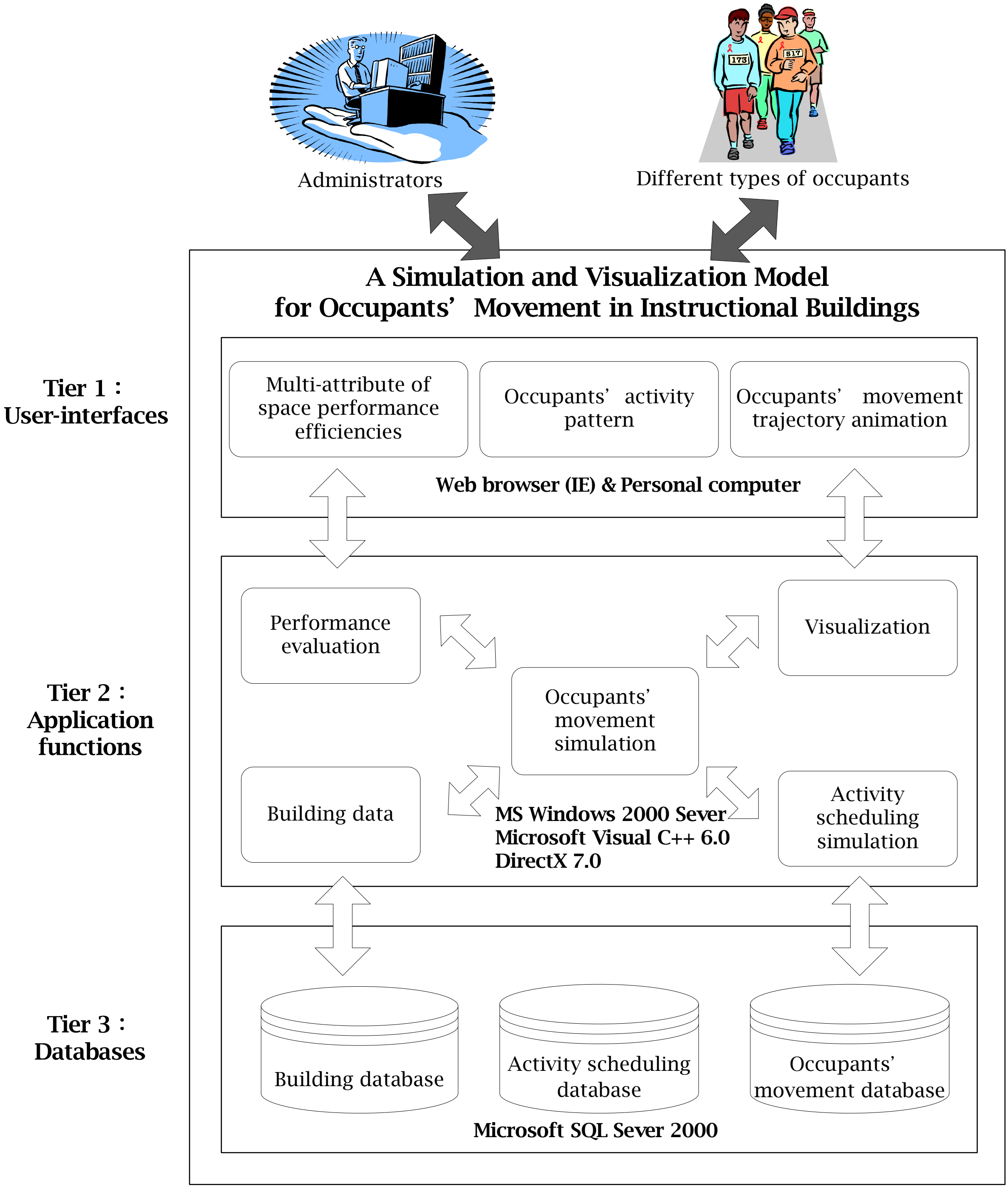

Fig. 6: System architecture.

5 CASE STUDY

To implement occupants' movement simulation, a case study was created to demonstrate its practical application. An instructional facility of the old building refurbishment is employed to demonstrate of occupants' movement simulation at National Chiao-Tung University. In the case scenario, the building would plan to renovate the 2nd floor of the left staircase unit (the staircase connected 2nd floor and 3rd floor). During construction, the staircase would be closed to use for occupants. In order to protect the occupants' safety, administrators would utilize the simulation system to investigate the effect of the staircase construction on occupants' movement and take appropriate the improvement measures.

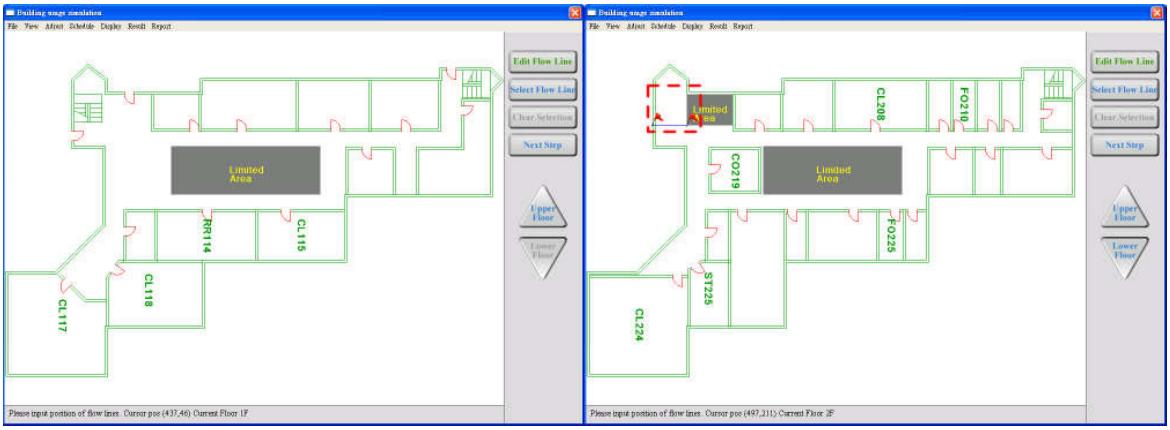

Fig. 7: Original situation—(a) 1F space layout, (b) 2F space layout.

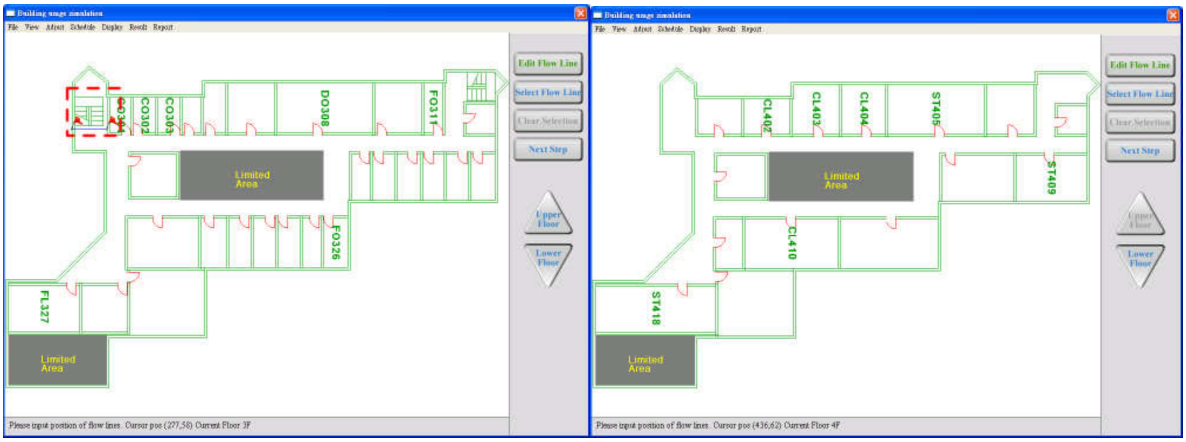

Fig. 8: Original situation—(a) 3F space layout, (b) 4F space layout.

5.1 Input Data

In this case, there are 4-story instructional facility building, one floor with three entrances, each floor are equipped with two staircase units, the internal space consists mainly of Classrooms, Conference Rooms, Professor Office, Master Research Office, Library, Administration Office and Professor Lounge unit, 1st floor atrium having an garden, 2 floor to the 4th floor of the middle region having an courtyard. An assumption of the research was that both constrained activities and non-constrained activities had not been affected by the left staircase renovation. First, users must download original behavior data of constrained activities and non-constrained activities to conduct occupants' movement simulation. Secondly, to express the 2nd floor left staircase unit impassable, the system input data must remove it from the original layout. Finally, the system input data had to add flow lines near the construction of the left staircase unit (the 2nd and the 3rd floor staircases) in order to observe the pedestrians flow. Upon the above-mentioned input data and the original functions layout of space, the case space layout was shown in Fig. 7 to Fig. 8.

5.2 Simulation Analysis

Based on original space layout and activities behaviors data, this research performed two different kinds of simulations in the same instructional building. One of the simulations is staircase renovation situation of pathway obstacle; the other is original situation of no obstacle, as shown in the following simulation results:

(1) Occupants' movement distance: Compared with original situation, the staircase renovation situation has significant increase movement distance in all types of occupants except the freshmen (3.42%) and sophomore (-3.74%) (see Tab. 2). The freshmen and sophomore participated in activities on the 1st and 2nd floor, so their movement distance value made nearly no difference during staircase renovation of the 2nd floor. However, the remainder of occupants joined in activities on the 3rd and 4th floor, they made a detour (using the 2nd floor of right staircase) to avoid using the left staircase. Therefore, it led to significant increase of the movement distance in the trend.

(2) Cumulative occupants flow: The cumulative flow is presented in Tab. 3. It found that there were 1,776 people for a week close to the 2nd floor of the left staircase construction site. This cumulative flow may be due to parts of occupants participated in activities on the 3rd and 4th floor. To improve walking safety in the instructional building, the research proposed following improvement measures to induce occupants as far as possible away from the left staircase of the 2nd floor during construction.

Occupants types		Movement distance (meter/people*week)		Difference (b.-a.)/a.
		a. Original situation	b. Staircase renovation	
Undergraduate	Freshman	9.27	9.59	3.42%
	Sophomore	17.91	17.24	-3.74%
	Junior	20.67	28.51	37.91%
	Senior	12.77	17.60	37.82%
Total movement distance of undergraduate		60.62	72.93	20.31%
Graduate student	Structure eng. student	74.76	105.96	41.73%
	Hydraulic eng. student	86.6	160.16	84.94%
	Surveying eng. student	64.12	84.20	31.32%
	Construction eng. and management student	82.8	89.64	8.26%
Total movement distance of graduate		308.28	439.96	42.71%

Tab. 2: Occupants' movement distance.

Position	Cumulative flow (people/week)			Difference (b.-a.)/a.	Difference (c.-a.)/a.
	a. Staircase renovation	b. Plan A	c. Plan B		
the 2nd floor of left staircase	1776	1190	198	-33.00%	-88.85%
the 3rd floor of left staircase	5	3	3	-40.00%	-40.00%
Total cumulative flow	1781	1193	201	-33.02%	-88.71%

Tab. 3: Cumulative flow near construction site.

5.3 The Improvement Measures of Simulation Analysis

To improve occupants walking safety in the instructional building, this research took the two improvement measures and re-simulation to induce occupants away from the renovation of 2nd floor left staircase. Improvement measures and its simulation results are described as follows:

(1) Plan A : Plan A planned to take one part constrained activity of space location changing from the 4th floor to the 1st floor, that is CL403 located the 4th floor were replaced by CL117 located the 1st floor.

(2) Plan B: In order to reduce occupants close to the construction site of 2nd floor left staircase , Plan B planned to temporarily close 1st floor left staircase and induce occupants to up and down stairs merely using the right side staircase. The system input data must remove the 1st floor left staircase unit from original layout, and the revised data of the space layout presented in Fig. 9 to Fig.10.

Based on occupants' movement simulation, both Plan A and Plan B shown effectively decrease occupants flow near the construction site compared to the staircase renovation situation (see Tab. 3). In addition, the simulation results showed that Plan B (-88.71%) were significantly superior to Plan A (-33.02%) in the total occupants flow reduction. In particular, Plan B need not adjust activities locations and need not consider these activities locations arrangement conflict with the other. Plan B was more easily performed in practice rather than Plan A. Overall, the results of Plan A and Plan B have been very positive for reducing the accidents probability.

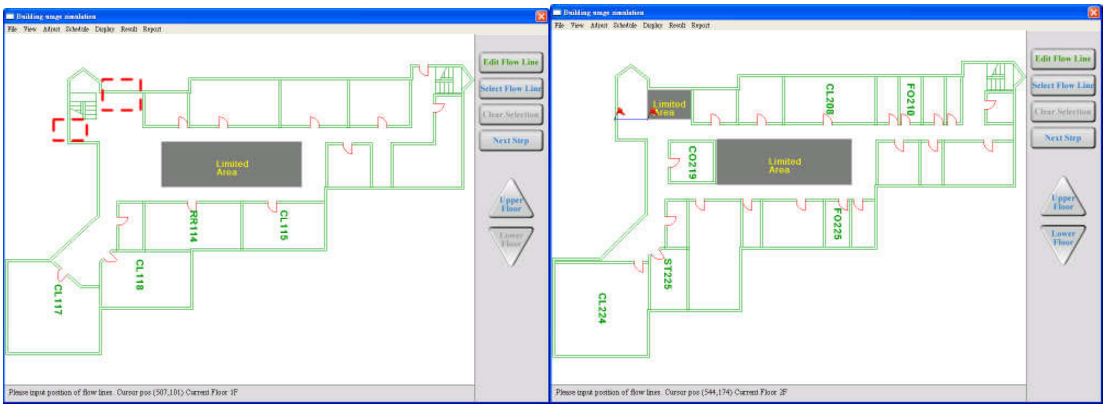

Fig. 9: Plan B—(a) 1F space layout, (b) 2F space layout.

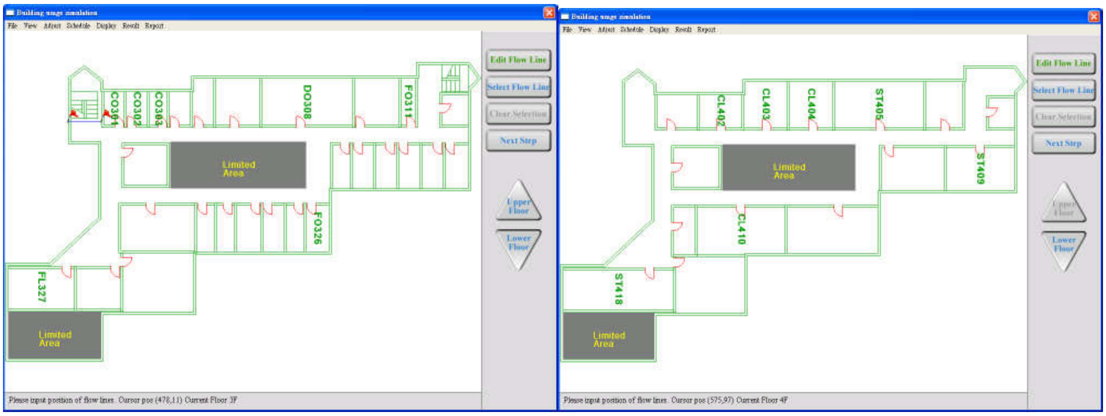

Fig. 10: Plan B—(a) 3F space layout, (b) 4F space layout.

6 CONCLUSION

As the resource of land reduces daily, building renovation is one effective method to redefine the use of the building and improve its efficiency. Traditionally, building renovation merely depended on architects and administrators. That is too subjective and easy to ignore occupants of activities behavior. Another way is to repeatedly conduct the physical occupants' movement simulation experiments for the different improvement measures via manual observation or automated records. Nevertheless, the experiments will be subject to require a lot of cost and time constraint to perform again and again physical simulation.

In this research, we have inducted a process model for activity scheduling and occupants' movement simulation in instructional buildings. Besides, we developed a system to implement the occupants' movement simulation and visualization in an instructional building. The system was used to adaptability assist administrators in analyzing occupants' usage of the space performance efficiencies and to take appropriate the improvement measures. Administrators would utilize them as evaluation tool when the space layout needs to rearrange function or the other pathway unit needs to renovate in an existing building.

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