Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Exploring the spatial arrangement of patient rooms for minimum nurse travel in hospital nursing units in Korea

Jisun Lee a,b, Hyunsoo Lee a,*, Mardelle McCuskey Shepley b

a Department of Interior Architecture and Built Environment, Yonsei University, Seoul 03722, Republic of Korea
b Department of Design and Environmental Analysis, Cornell University, Ithaca, NY 14853, USA

Received 22 March 2020; received in revised form 15 June 2020; accepted 16 June 2020

Abstract With increasing demands on medical care services, one of the trends is the mixed patient room arrangement of single/double-bed and multi-bed rooms in a nursing unit on the same floor. This influences nurse-to-patient assignment and often causes an unbalanced workload and longer travel distances for nurses. The objective of this study was to investigate how floor configuration and room density influence nurse travel in the hospital’s medical surgical units in Korea. This study presented a novel approach to measure nurse travel distances in eight existing nursing units. The agent-based simulation was conducted to model nurses’ walking trials, and the distance of one nurse travel to assigned patient rooms was measured for each nurse. With revisions in the spatial arrangement of patient rooms, locating multi-bed rooms near the nurse station, symmetric room layout centering the nurse station, and planning both single/double-bed and multi-bed rooms on one side of corridors, nurse travel distance decreased more than 15%. This study contributed to the knowledge of agent-based simulation as an evaluation framework for spatial analysis. Apart from application to Korea, these results are particularly of interest in countries where private patient rooms are not commonly economically feasible.

© 2020 Higher Education Press Limited Company. Publishing Services by Elsevier B.V. on behalf of KeAi. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
1. Introduction

Nurses are one of the most valuable resources in the healthcare industry, and they are responsible for direct patient care. Nurses’ roles and responsibilities are essential in meeting the high demands of patient care and advancing improved patient outcomes (Institute of Medicine, 2011). However, the healthcare industry is facing a growing shortage of nursing staff and a high staff turnover rate, while the high demand for quality care services persists (Health Resources and Services Administration, 2013). The primary reason nurses leave their jobs is a highly demanding workload (Mazurenko et al., 2015; Tao et al., 2015). Their work is physically and emotionally intense with heavy daily duties, high emotional exhaustion, and physical burnout, which results in nurse dissatisfaction with their jobs (Aiken et al., 2002; Faller et al., 2011). Factors such as extended working hours, continuous working shifts, lack of rest breaks, and long walking distances contribute to nurse fatigue and stress (Hendrick and Chow, 2008; Pati et al., 2008; Witkoski and Dickson, 2010). Poor environments result in nurse stress and a reduced sense of well-being (Hendrick and Chow, 2008; Ulrich et al., 2004, 2008; Zimring et al., 2004). In a nursing unit, long travel distance has been one of the most critical issues that impact nurse fatigue and stress (Chaudhury et al., 2009; Zborowsky et al., 2010). Nurse travel is also directly related to the time spent on patient care. The literature indicates that nurses who spend more time walking spend less time at patients’ bedsides (Hendrick et al., 2008; Shepley and Davies, 2003; Trites et al., 1970; Ulrich et al., 2004). Researchers have tried to evaluate how much walking distance can be shortened and how much time saved, which can potentially be directed to patient care (Gurascio-Howard and Malloch, 2007; Lu and Zimring, 2012; Pati et al., 2012, 2015). Improving the environment to support a well-balanced patient load and reduce walking distance is necessary for nurses’ well-being as well as secured time for patient care.

This study examined the effects of spatial features on nurse walking distance (NWD), particularly focusing on the arrangement of patient rooms. The patient room locations need to facilitate effective access from the center of the ward, i.e., the nurse station, and other assigned patient rooms for minimum nurse travel (Nazarian et al., 2018). Over the last two decades, trends in patient room types have moved towards the preference for single-occupancy patient rooms. Single-occupancy rooms have been considered to be more appropriate than multi-occupancy rooms because they enhance privacy, prevent infections, reduce noise, and incorporate space for families (Chaudhury et al., 2005, 2006). However, the majority of patient room types differ by country depending on the level of medical demand services and cultural and financial structures. Multi-occupancy rooms are still in the majority in many countries, including the UK, Germany, and Korea (Choi et al., 2017; Maben, 2009; Scott et al., 2012; Wagenaar and Mens, 2016). In Korea, with high medical demands and limited land property, most general hospitals consist of a mix of single, double, and multi-bed rooms in one nursing unit. Experts report staff challenges with single room-only hospitals (Stephenson, 2015), and argue for a flexible mix of room types for varied preferences and clinical goals (Pennington and Isles, 2013; Trant, 2010) Notably, in an epidemic condition like COVID-19, flexible patient room occupancy levels are needed. Healthcare facilities with single rooms only did not meet the demand, and patient beds were placed in corridors. In the mixed arrangement, both single/double-bed and multi-bed rooms are assigned to each nurse for balanced workload (Choi et al., 2014, 2017; Shin and Kang, 2016). In the racetrack type units where single/double-bed and multi-bed rooms are located on the opposite sides of the floor (with the service core in the middle), nurses have to travel along both sides to care assigned patients. However, studies on the relationship between patient room types and nurse travel distance are lacking.

Nurses’ movement patterns relate to nurse experience, patient care mix reflecting patient condition and patient load, and most of all, the location of assigned patient rooms (Choudhary et al., 2010; Heo et al., 2009; Nanda et al., 2015). The distance between assigned rooms and patient room to patient room circulation are major contributors to nurse walking (Pati et al., 2008). In this paper, an “assignment” refers to a set of rooms assigned to a nurse. Current healthcare models represent proximity between spaces, typically reflecting a simple path for an effective sequence of activities. This is adequate in cases where the patient and staff movement are explicitly determined, such as the outpatient unit, emergency department, and operation room. However, for predicting and simulating movement in inpatient units, the simple approach of point-to-point distance is limited, because nurses move continuously during a shift, rarely following the same pattern. In this study, a novel approach of agent-based modeling is applied as a process-oriented analysis methodology to reflect a sequence of nurse activities. This study evaluates the effect of different layouts of hospital nursing units on nurse movement patterns, and also contributes to the field of agent-based simulations. In this study, a simulation-specific approach is taken to provide strong evidence to healthcare providers regarding the location of patient rooms in a nursing unit.

2. Literature review

2.1. Spatial features, nurse-patient assignment, and nurse travel distance

The spatial relation between the nurse station and patient rooms is one of the most critical elements influencing nurse travel (Cai and Zimring, 2012; Gurascio-Howard and Malloch, 2007). The literature reports that the most traveled paths of nurses are between the nurse station and patient rooms (Acar and Butt, 2016; Nazarian et al., 2018). In an observational study, the travel between the nurse station and patient rooms took 34.5% of total nurses’ travel during a 12 h shift (Acar and Butt, 2016). An individual nurse walks an average of 2.4–3.4 miles per daytime shift (Hendrick et al., 2008; Shepley and Davies, 2003), and this distance can be as much as 6 miles (Pati et al., 2012).
The spatial arrangement of patient rooms for minimum nurse travel

Hendrich et al. (2008) described how nurse travel distance, time with patients, and workload varied between different unit layouts in 36 medical-surgical units: 19 racetrack type units, 12 double-loaded units, single corridor, and five radial type units. It was obvious that the travel distance and patient time among nurses varied more within the same unit than between units. They found no statistically significant correlation between unit type, travel distance, and patient time; however, the difference in nurse travel distance between spatially contiguous patient assignment and non-contiguous room assignment was significant (Hendrich et al., 2008). Nurse managers and directors even walk longer than the average nurses walk, and long walking distances are a challenge for care coordination and overall management (Nanda et al., 2015). The variability of distance traveled between individual nurses on the same unit is often greater than the variance across different hospital units (Hendrich et al., 2008).

One of the causes of the large variability in distances traveled among individual nurses on the same unit is the spatial properties of room assignments. The associated spatial properties affect nurse travel patterns and distance traveled. Nurses travel between assigned patient rooms, nurse stations, and supply rooms (Butt et al., 2004). The nurse-to-patient assignment involves a time-consuming and complicated process with many considerations, such as patient acuity, patient preference, continuity of care, and nurse experience. The patient’s location in the unit is one of the primary factors to consider for patient assignments and often more critical than nurse experience and expertise (van Oostveen et al., 2014). Patient rooms that lie outside the main circulation of a nursing unit contribute to added walking distance to and from the patient rooms to nurses’ areas (Pati et al., 2008), and patient assignments in two corridors result in additional walking (Gurascio-Howard and Malloch, 2007). The travel from the center of the ward, i.e., the nurse station, and other assigned patient rooms impacts walking distance (Nazarian et al., 2018).

In nursing units with a flexible mix of room types for varied preferences and clinical goals, the arrangement of room types is one of the causes for scattered patient assignments. Even though patient assignments are complicated, for balanced workload, assigning both single-double-bed and multi-bed rooms is prevalent in Korea where most hospitals consist of a mix of room types within the same unit (Choi et al., 2014, 2017; Shin and Kang, 2016). Patient room assignments are a basis for nurse travel, and a nurse is required to establish movement pattern strategies according to the spatial relationship between patient rooms and nurses’ areas (Heo et al., 2009). Also, the number of visits to patients is correlated with spatial properties (Choudhary et al., 2010; Hendrich et al., 2008; Heo et al., 2009).

2.2. Agent-based modeling for pedestrian walking simulation

Agent-based simulations have been widely applied to simulate pedestrian walking behaviors in architecture from a building to an urban scale. They are often employed to generate realistic and autonomous pedestrian walking behavior. Using simple rules to simulate the decision-making processes while interacting with environments, agent-based models perform high levels of correlation to human behavior. Various successful models, such as the cellular automata (Dijkstra and Timmermans, 2002), social force (Helbing and Molnar, 1995), boids-type behavior (Reynold, 1987), shortest path (Hoogendoorn and Bovy, 2004), and exosomatic visual architecture (Turner and Penn, 2002) have been described in the literature.

Previous case studies find strong correlations between agent-based models with human pedestrian behavior in comparison to real-world observations and computing movement models (Batty, 2001; Helbing et al., 2002; Turner and Penn, 2002; Turner, 2007; Torrens, 2012; Yang et al., 2011; Vizzari et al., 2015). Due to the similarity of agent-based models and human movement behavior, evacuation modeling and wayfinding are the most common consolidated areas in which agent-based models are employed (Najian and Dean, 2017; Orellana and Alsayed, 2013; Raubal, 2001a, 2001b; Vizzari et al., 2020). Although many researchers have conducted agent-based models using aggregated data, some researchers focus on individual human movement level. Orellana and Alsayed (2013) carried out research covering on-site observations and virtual simulations of pedestrian walking and demonstrated a strong relation between observed and virtual pedestrian movement at an individual level. Traditionally, in nursing unit studies, walking distances have been estimated based on point-to-point linear proximity between key areas (Hendrich et al., 2008; Shepley and Davies, 2003; Pati et al., 2012; Yi and Seo, 2012). Among Korean inpatient unit case studies, Shin and Kang (2016) assessed nurse walking distances using traditional point-to-point linear measurement based on field interviews of nurses’ patient room assignments. However, human walking behavior typically does not follow the centerline and makes a curve at corners to move along the shortest path to a destination point (Helbing et al., 2001). Agent-based modeling can accommodate multiple path options of every nurse and, at the same time, reflect more realistic human behavior patterns.

2.3. Nurse travel assessment

Most studies on nurse travel assessment are based on field observations (e.g., Choudhary et al., 2010; Hendrich et al., 2008; Seo et al., 2011; Shepley and Davies, 2003; Shin and Kang, 2016; Sturdivant, 1960; Yi and Seo, 2012), and few employ simulation-based experiments (Nanda et al., 2015; Pati et al., 2015). For visualizing and measuring walking distances within buildings using a computational method, Dym et al. (1988) suggested travel-distance algorithms that examine a hospital floor plan via defining the shortest path between each wall’s midpoints. Lee et al. (2010) employed a metric graph structure to represent building circulation and calculated walking distances with the shortest path and interpreted the building shape with a buffered space-boundary polygon reflecting half the width of a person’s shoulder from a wall as minimum buffer distance. Nanda et al. (2015) combined field research and spatial parametric modeling tools in their study on assessing nurse walking distance in a medical-surgical unit. A Rhino/
Grasshopper model was developed to assess nurse walking distance from every patient room to the support areas.

Observation studies on nurse walking distance reveal the complexity of their travel. The variations between the sequence of activities, frequencies of visits, unexpected interruptions for minor tasks during patient visits are variable. However, the literature agrees that the most frequently visited areas are patient rooms (Acar and Butt, 2016; Hendrich et al., 2008; Nanda et al., 2015; Nazarian et al., 2018; Pati et al., 2012) and the proximity between the nurse station and the patient room is critical (Cai and Zimring, 2012; Gurascio-Howard and Malloch, 2007). Also, studies predicting and computing nurses' movement suggest that nurse walking routes are more relevant when based on a sequence of activities rather than simple proximity measures (Choudhary et al., 2010; Heo et al., 2009; Nanda et al., 2015; Shin and Kang, 2016).

3. Methods

A novel spatial analysis tool was implemented to visualize nurse walking behavior and spatial data on the current environment of hospital inpatient units. Using a parametric model in Rhino/Grasshopper, an agent-based simulation was conducted to assess each nurse’s walking distance. The agent-based simulation generated virtual nurses’ walking trails, and the parametric algorithm measured the distance (NWD) of each walking trail. A visualized nurse walking trail reflected one patient visit “round” of each nurse, which was regularly taken for activities such as doctor visits, shift handover, or medication during a shift. Those were paths from the nurse station toward assigned patient rooms, stopping by a clean supply/medication room, and returning to the nurse station. The selected cases included typical medical-surgical inpatient units of eight general hospitals (Fig. 4). This article represented partial findings of a doctoral dissertation (Lee, 2019), which applied mixed methods of data collection: literature review, case studies, and simulations.

3.1. Agent-based modeling

In the agent-based simulation, virtual agents represent nurses. Nurses’ walking trails were generated and measured in a Rhino modeling space of each unit. The Grasshopper plug-in program "PedSim" is used to model nurse walking behavior. PedSim has been used to simulate walking paths in healthcare facilities for evaluating accumulated walking trails of patients (Lee and Lee, 2020). Fig. 1 demonstrates how the possible routes where agents can move within a given environment are analyzed in PedSim. In the simulation, the building components, such as walls and fixed furniture, are set as obstacles, i.e., a series of closed polygons that form a space boundary. The edges and vertices are automatically generated at a buffered distance from the building polygons, and the edges become the possible routes that agents can choose. The buffered distance is a half-width of a shoulder and reflects the distance humans offset from walls to avoid collisions while walking in indoor space. PedSim also employs multiple forces for agents’ walking behavior. It is based on the social force model (Helbing and Molnar, 1995) with agents driven by multiple forces, namely a target force, person repulsion, and obstacle repulsion for their basic movement mechanism, and an anticipatory collision avoidance force to make agents aware of potential collisions and take actions earlier (Wang, 2019). In the simulation, an agent chooses the shortest path among the possible routes within the given environment and moves to a target point, avoiding collisions with multiple forces (Wang, 2019).

In the agent-based modeling, nurse travel is set with a sequence of movements per patient assignment. The movement sequence is programmed by a set of parameters: visit locations, number of visits, and a flow of the assignment. The methodology is process oriented. When the movement path is visualized on the layout following the key sequence of movement, the distance is measured automatically by the parametric components. The agents also
have a vision, and they move to the target point in possible visible routes.

This study simulates nurse travel based on the most obvious sequence of visits during a shift, which is a patient visit round. Each nurse movement path reflects a set of patient assignments. Four or five different patient rooms, which are assigned to one nurse, are visited in each round, and four or five sets of assignments cover all the unit’s rooms. The simulation process (Fig. 2) for a patient visit round is as follows: (1) the agent finds the shortest path to the destination point, (2) it visits points of interest if it sees those and avoids obstacles and other agents on its way, and (3) goes to the destination point. In the simulation, an agent, which is a nurse, (1) travels from a starting point: the nurse station, (2) visits points of interest: the supply/medication room and assigned patient rooms of each nurse, and (3) goes to a destination point: the nurse station, avoiding obstacles such as walls and furniture in the plans (Fig. 3).

3.2. Case description

3.2.1. Unit characteristics
The typical double-loaded corridor type nursing unit was the standard design for many years from the early design of hospital wards, because of the need for cross-ventilation and natural lighting. With an increase in the demands for hospitals, planners have tried various plan configurations to achieve efficient activity patterns. The more compact plans, such as radial (Valley Presbyterian Hospital in California and Brigham And Women’s Hospital in Boston), L-shaped (Aspirus Wausau Hospital in Wisconsin), square (Providence Hospital in Alaska), and triangular-shaped (Jacobs Medical Center in San Diego) nursing units have been developed with groupings of concentric support areas in inpatient units (Kobus et al., 2008). Valley Presbyterian Hospital in California (1956) developed the first compact radial type unit, and recently Brigham And Women’s Hospital in Boston developed radial intensive care units. Recent trends have shown a shift toward the racetrack type. Racetrack type design maximizes the perimeter wall of the unit while providing moderate visibility and accessibility from the nurse working area to patient rooms. Another trend is toward pod configuration, which provides better patient monitoring opportunities (Cama, 2009; Hamilton and Shepley, 2010; Thompson et al., 2012). However, in Korea, with its enormous scale and high land prices, high-rise hospitals with a racetrack or triangular shape units are the most common.

This study included four rectangular and one triangular-shaped inpatient unit layouts of the most highly ranked hospitals among 42 tertiary care hospitals in Korea (Ministry of Health and Welfare, 2018) and three representative triangular layouts from secondary care
hospitals (Fig. 4). Among the selected medical-surgical inpatient units of eight hospitals, four are in Seoul and four in other cities. The typical floor plans of the units follow the criteria: 40 to 50 beds per unit, 500 to 1000 inpatient beds in total, and being built after 2000. Each ward floor has two nursing units and two centralized nurse stations, two medication and clean supply rooms, one nourishment room, two soiled linen rooms, and two equipment rooms at the center of each unit. Each nursing unit had a double-corridor design with a triangular or rectangular shape, and mixed arrangement of patient room types: single, double, or multi-occupancy (Tables 1 and 2). The characteristics of the units were categorized by (1) unit shape - triangular or rectangular and (2) location of the nurse station - near the elevator core or center of the unit.

Fig. 4 Hospital ward floor plans: four in triangular shapes and four in rectangular shapes, and two nursing units located on each floor except Unit 6.
3.2.2. Nurse-patient ratio

A nursing unit refers to the number of beds the nurses in a group are accountable to take care of, and the units of general hospitals in Korea have 40–60 beds per nursing unit due to a large number of patients. The staff to patient ratio ranges from 1:7 to 1:12 for registered nurses (National Health Insurance Service, 2019). The nurse-patient assignments of selected units are based on Shin and Kang’s (2016) research on the nurse-patient assignments. The nurse-room ratio of the eight units was set with respect to three criteria: (a) nurse-patient ratio was 10-12 patients per nurse, (b) both single/double-bed patient rooms and multi-bed patient rooms were assigned to one nurse for workload balance, and (c) all patients in a single room assigned to the same nurse (Table 3).

3.2.3. Nurse movement setting

To compare the nurse travel distance between units, one patient visit “round” of each nurse was measured in the simulation. In the delivery of patient care and related activities, the locations nurses visit may vary based on urgent medication and patient requests. According to empirical studies on the traveled paths of nurses (Acar and Butt, 2016; Kim and Chai, 2018; Nanda et al., 2015), the most frequently visited paths during both day and night shifts are between: (i) patient rooms and nurse station; (ii) nurse station and clean supply/medication room; and (iii) patient rooms and clean supply/medication room, in this order. In this study, the simulation setting was limited to one patient visit round of each nurse to the assigned patient room visits at each shift change, excluding irregular travel. The distance to the patient room doors was calculated, and the movement inside the patient room was excluded from the measured distance.

4. Results

4.1. Nurse walking distance

Nurse walking trails for one round of each nurse (N = 33) were simulated, and the distance of each round path was measured (Fig. 6 and Table 4). The shortest average NWD of each unit was measured in Unit 4, and the longest in Unit 7.
In the triangular units (Fig. 6). Therefore, the distance to nurse stations were closer to the center of the units rather than the center of the units. The simulation results revealed that these measures did not consequently result in longer NWD. The units of the long distances from nurse station to end of the unit (NS to EU) were Units 1, 6, and 8, and of the long perimeter (length of patient room walls on door side) were Units 3, 6, and 8, compared to the average (Fig. 7 and Table 4). However, Unit 1 showed a short NWD with a long NS to EU distance, while Unit 7 showed the longest NWD with one of the shortest NS to EU distance. The average ranges of NWD were captured in Units 3 and 6 despite the long perimeter length. Unit 6 showed an average range of NWD with a long NS to EU distance and perimeter length.

4.3. Patient room arrangement

One of the critical spatial attributes influencing nurse travel distance was the patient room arrangement. In the cases where single/double-bed patient rooms and multi-bed rooms were planned in the same unit, an equivalent number of single/double-bed and multi-bed patient rooms were to be assigned to each nurse for balanced workload distribution. In Units 5, 7, and 8, where single/double-bed and multi-bed rooms were located in separate two hallways, the nurses had to move up and down across the center support areas to visit patients in two corridors. These geographically non-contiguous patient assignments caused long travel distances. Among the rectangular units, Unit 6 presented an average level of NWD despite the lounges located in between patient rooms, the long perimeter of patient rooms, and long NS to EU distance. Unit 6 had the patient room arrangement, which supported a contiguous patient assignment plan, locating a mixed arrangement of patient rooms along the same corridor, as nurses get assigned for patient rooms of both single/double-bed and multi-bed rooms. However, in Unit 3, even though both room types were located along the same corridor, they were placed in distant locations. Consequently, Unit 3 presented non-contiguous patient assignments with longer NWD than others among the triangular units. The patient room arrangement contributed to the geographical continuity of the nurse-patient assignment, and non-contiguous patient assignments often caused inefficient travel distances for nurses. Therefore, the spatial arrangement of patient room types was one of the critical features for nurse walking efficiency, as this was highly related to the patient assignment plan.

4.4. Revised patient room arrangements to reduce nurse travel distance

The frequency of nurse visits to patient rooms from the nurse station was higher in double-bed rooms than single-bed rooms (Nazarian et al., 2018), which means locating multi-bed patient rooms closer to the nurse station would reduce nurse walking. To explore the effects of patient room arrangement on NWD, the room arrangements of three rectangular units, Units 5, 7, and 8, were revised to support geographically contiguous nurse-patient room assignment through the following modifications:

- With a categorized comparison of two groups of ‘contiguous’ and ‘non-contiguous’ patient room assignments, the average NWD was 46.34 and 59.98 m (Table 5). This study defined the nurse-patient assignments between immediately adjacent patient rooms as “contiguous”, and with nearby but not contiguous neighboring patient rooms as “non-contiguous”. Obviously, the units with geographically contiguous patient room assignments had shorter NWD than the units with non-contiguous patient room assignments. Unit 3, a triangular unit with a non-contiguous patient room assignment, had a longer NWD than other triangular units. Unit 6 was the only rectangular unit with a contiguous patient assignment, and it had a shorter NWD than other rectangular units. Unit 6 had the lounges located in the middle of the patient room sections, which increased the distance between the nurse station and patient rooms.

- Considering nurses travel between the nurse station and assigned patient rooms approximately fourteen times during a shift (Kim and Chai, 2018), the variations will be even more substantial. Unit 4 shows the most equivalent distances among nurses within a unit. Units 3 and 7 show lower SD than the average; however, Unit 7 had the longest average NWD, which indicated that nurses in Unit 7 walked more than nurses in other units. The NWD in Unit 6 varied in the largest differences among nurses, and the variations of NWD among nurses in Units 1, 2 were also larger than other units. Units 7 and 8 had long average NWD, and variations of NWD within the units were at the average level.

Although the triangular units showed shorter NWD than the rectangular units, unit typology may not be the most fundamental reason for the short walking distance. The simulation results presented strong evidence that the average NWD was shorter in the units with a nurse station located at the center of the unit (Table 5), and the locations of nurse stations were closer to the center of the units in the triangular units (Fig. 6). Therefore, the distance to the patient rooms from the nurse station was shorter in the triangular units than the rectangular units. In rectangular units, the nurse station was closer to the unit entrance rather than the center of the units.

With a categorized comparison of two groups of 'contiguous' and 'non-contiguous' patient room assignments, the average NWD was 46.34 and 59.98 m (Table 5). This study defined the nurse-patient assignments between immediately adjacent patient rooms as "contiguous", and with nearby but not contiguous neighboring patient rooms as "non-contiguous". Obviously, the units with geographically contiguous patient room assignments had shorter NWD than the units with non-contiguous patient room assignments. Unit 3, a triangular unit with a non-contiguous patient room assignment, had a longer NWD than other triangular units. Unit 6 was the only rectangular unit with a contiguous patient assignment, and it had a shorter NWD than other rectangular units. Unit 6 had the lounges located in the middle of the patient room sections, which increased the distance between the nurse station and patient rooms.

4.2. Distance from nurse station to end of unit and perimeter of patient rooms

The simulation results revealed that these measures did not consequently result in longer NWD. The units of the long distances from nurse station to end of the unit (NS to EU) were Units 1, 6, and 8, and of the long perimeter (length of patient room walls on door side) were Units 3, 6, and 8, compared to the average (Fig. 7 and Table 4). However, Unit 1 showed a short NWD with a long NS to EU distance, while Unit 7 showed the longest NWD with one of the shortest NS to EU distance. The average ranges of NWD were captured in Units 3 and 6 despite the long perimeter length. Unit 6 showed an average range of NWD with a long NS to EU distance and perimeter length.
The spatial arrangement of patient rooms for minimum nurse travel

Fig. 6 Nursing unit layouts with simulated nurse walking trails. Nurse-to-patient assignment marked in each room.
1) Symmetric room layout centering the nurse station, 2) Mixed planning of single/double-bed and multi-bed patient rooms on one side of the corridor, and 3) Multi-bed rooms as near as possible to the main nurse station to shorten nurse travel.

In Unit 5, two multi-bed patient rooms on the upper corridor were moved to the lower corridor for nurses to care for patients in a single corridor. In Units 7 and 8, similar changes to the layouts were made. One patient visit round was simulated for each nurse, and the travel distance was measured (Tables 6 and 7). A notable reduction in NWD was evident for all three units, with around 15% decrease in the revised layouts. Of the three units, Unit 7 had the largest difference. In Unit 7, the average NWD decreased from 68.97 to 55.95 m for one round, with an 18.88% reduction in distance. Also, SD decreased from 10.21 to 3.84, which is a noticeable improvement for equivalent NWD among nurses within Unit 7. In Units 5 and 8, the reduction was also evident: the averages of NWD decreased by 14.64% and 16.31%, respectively. However, SD slightly increased as the shortest NWD further decreased. Considering this was based on a single trip, the reduction of NWD would be more substantial with multiple trips in real situations. Based on the results, mixed planning of single/double-bed rooms with multi-bed rooms on one side of the corridor with consideration of contiguous nurse-patient room assignment influenced shorter nurses’ travel distance.

### Table 4  Nurse walking distance (m) for one patient visit round from nurse station to assigned patient rooms.

| Unit | Nurse-patient assignment | Avg. | Total | SD | P | NS to EU |
|------|--------------------------|------|-------|----|---|----------|
| N-1  | N-2                      | N-3  | N-4   | N-5 |   |          |
| 1    | 32.91                    | 41.84| 38.13 | 67.34| – | 45.06    | 180.22  | 15.30 | 72.70 | 33.70 |
| 2    | 26.06                    | 30.63| 49.63 | 61.78| – | 42.03    | 168.1   | 16.66 | 56.54 | 26.15 |
| 3    | 62.38                    | 53.46| 36.11 | 60.23| 46.18| 51.67    | 258.36  | 10.76 | 90.13 | 27.85 |
| 4    | 45.37                    | 46.64| 30.46 | 43.75| – | 41.56    | 166.22  | 7.49  | 61.65 | 22.70 |
| 5    | 57.28                    | 44.02| 71.35 | 48.18| – | 55.21    | 220.83  | 12.10 | 67.97 | 27.45 |
| 6    | 42.93                    | 72.8 | 37.88 | 73.26| – | 56.72    | 226.87  | 18.95 | 82.20 | 38.00 |
| 7    | 81.45                    | 70.98| 56.83 | 66.63| – | 68.97    | 275.89  | 10.21 | 72.50 | 25.34 |
| 8    | 81.51                    | 53.05| 53.34 | 68.31| – | 64.05    | 256.21  | 13.65 | 79.40 | 36.30 |
| Average |                          |      |       |     |    | 53.16    | 219.09  | 13.14 | 72.89 | 29.69 |

Note. (N: Nurse-patient assignment, SD: Standard deviation, P: Perimeter of patient room walls on the door side, NS to EU: Longer distance from the center of nurse station (NS) to end of the unit (EU)).

### Table 5  Comparison between units grouped according to unit shape, NS location, and patient assignments.

| Features                  | Unit No. | Avg. NWD | Avg. SD | Avg. Total |
|---------------------------|----------|----------|---------|------------|
| Unit shape                | Triangular| 1, 2, 3, 4| 45.08   | 12.55      | 193.23     |
|                           | Rectangular| 5, 6, 7, 8| 61.24   | 13.73      | 244.95     |
| NS/CR location            | Center   | 1, 2, 3, 4, 7| 49.86  | 12.09      | 209.76     |
|                           | Near Entrance | 5, 6, 8   | 58.66   | 14.90      | 234.64     |
| Patient Assignment        | Contiguous| 1, 2, 4, 6| 46.34   | 14.60      | 185.35     |
|                           | Non-contiguous| 3, 5, 7, 8| 59.98   | 11.68      | 252.82     |

1) Symmetric room layout centering the nurse station, 2) Mixed planning of single/double-bed and multi-bed patient rooms on one side of the corridor, and 3) Multi-bed rooms as near as possible to the main nurse station to shorten nurse travel.

**Fig. 7**  Comparisons of NWD of each unit: average, longest, shortest NWD, and SD measures. The x-axis represents the unit number and y-axis the distance in meters.
Table 6  Nurse walking trails on existing layouts and modified patient room arrangements.

| Unit | Existing layout | Revised layout |
|------|-----------------|----------------|
| 5    | ![Diagram](image) | ![Diagram](image) |
| 7    | ![Diagram](image) | ![Diagram](image) |
| 8    | ![Diagram](image) | ![Diagram](image) |

Table 7  NWD of existing and revised layouts with patient room arrangement changes.

| Unit | N-1 | N-2 | N-3 | N-4 | Avg. | Total | SD | DA (%) |
|------|-----|-----|-----|-----|------|-------|----|--------|
| 5    |     |     |     |     |      |       |    | -14.64 |
| Existing | 57.28 | 44.02 | 71.35 | 48.18 | 55.21 | 220.83 | 12.10 |        |
| Revised | 28.72 | 48.96 | 61.18 | 49.66 | 47.13 | 188.52 | 13.49 |        |
| 7    |     |     |     |     |      |       |    | -18.88 |
| Existing | 81.45 | 70.98 | 56.83 | 66.63 | 68.97 | 275.89 | 10.21 |        |
| Revised | 59.24 | 52.97 | 59.3  | 52.3  | 55.95 | 223.81 | 3.84  |        |
| 8    |     |     |     |     |      |       |    | -16.32 |
| Existing | 81.51 | 53.05 | 53.34 | 68.31 | 64.05 | 256.21 | 13.65 |        |
| Revised | 62.26 | 41.92 | 76.36 | 33.87 | 53.60 | 214.41 | 19.31 |        |

Note. (DA: the difference between the average NWD of the existing and revised layouts).
5. Discussion

5.1. Patient assignment and nurse travel distance

The results of this study indicated that changes in spatial features, such as nurse station location, patient room arrangement, affect nurses’ walking distances, and the size of the units, may not merely increase nurse travel with supportive spatial planning. Also, this study discussed the relationship between nurse-patient room assignment and nurse travel distance. Nurse travel is based on the patient assignment during a shift, and the assignment frequently involves geographically non-contiguous patient rooms (Pati et al., 2008). Non-contiguous patient room assignments often increase walking for nurses (Hendrich et al., 2008). Although it is assumed that nurses are assigned to a set of contiguous patient rooms, actual patient assignments vary in regard to other factors, such as the acuity level of a patient, competency of a nurse, and a nurse-to-patient ratio (Pati et al., 2008). This study emphasized that patient assignment is one of the critical factors to consider in the design stage for reducing nurses’ walking, even though it is an operational issue and not a spatial issue.

With an understanding that the actual patient assignment may vary and not result in contiguous rooms, depending on the balance between criteria, this study explored the optimal layout that healthcare designers could provide to support contiguous room assignments, initially. In a mix of single/double and multi-bed patient rooms in one nursing unit, this study demonstrated two spatial factors impacting minimum nurse travel distance: 1) locating multi-bed patient rooms near the nurse station and 2) planning both single/double-bed and multi-bed rooms on one side of corridors instead of separating single/double-bed and multi-bed patient rooms on two different corridors.

5.2. Patient room arrangement, visibility, and noise level

The critical design factors in a nursing unit design are space layout that supports efficient nursing activities, reduced walking distances, organized supply areas, controlled noise level, and visibility with ease of supervision (Zbrowsky et al., 2010). This study has focused on the issue of walking distances, and the results demonstrated that planning multi-occupancy patient rooms near the nurse station were more effective in reducing nurse travel distance. This approach can also impact patient visibility and noise level. More patients are easily visible and accessible from the nurse station when locating multi-bed patient rooms near the nurse station (Lee, 2019). A high noise level is often reported around the nurse station, and patients who prefer single-occupancy rooms would benefit from being at a quieter location than around the nurse station.

5.3. Patient visibility versus visual control over the entrance

The nurse station is a central hub for nursing activities in a hospital unit and the primary work area of each unit. The location and distance of the nurse station to the patient room has been considered as a critical influence on nurse walking distance. Planning the nurse station closer to the center of the units is a convincing design strategy to keep nurse travel distance to a minimum, especially in a linear and less concentric rectangular unit. However, one of the reasons for positioning the nurse station close to the entrance would be the high need for visual control over the entrance. Even though it is out of the scope of this study, planning both the entrance and nurse station at the center could be a robust design strategy to keep nurse travel distance to a minimum and gain sufficient visibility to the entrance. Among the cases of this study, Unit 5 has the nurse station close to both entrance and center of the unit. However, patient visibility was low due to the orientation of the nurse station, which was facing the entrance rather than patient rooms. In Unit 5, despite the long perimeter length, the NWD was at the average level. It could be a good strategy to develop this unit into a hybrid nursing station model to improve patient visibility. It will also satisfy visual control to the entrance and patients, as well as achieving moderate NWD.

5.4. Other implications of agent-based modeling

Representing the process of how nurses’ movements are made, this study attempted to contribute to the field of agent-based simulations. While classic population-level modeling has been limited in its ability to integrate individuals’ decision-making, this study expanded the application areas of agent-based modeling to an individual level. Even though this study has limited the application strategy to minimum nurse travel, agents can be set as patients, physicians, staff, visitors, and caregivers within the facilities as an expanded approach. In this sense, an agent can also be set with any spatial factors in the simulation, such as noise level, visibility, and patient preferences. Planners can develop a simulation model with a mixed approach for optimized layout planning. Simulation of healthcare in the design process is useful because it allows designers and planners to analyze the performance of the facilities at an organizational level and also enables relative comparisons among design options.

6. Conclusions

This study investigated how floor configuration and room density influenced nurse walking distance in the hospital’s medical-surgical units with the intent of reducing staff fatigue and securing more time for nurses to spend on direct
The authors have no conflicts of interest to report.

References

Acar, I., Butt, S.E., 2016. Modeling nurse-patient assignments considering patient acuity and travel distance metrics. J. Bio-med. Inf. 64, 192–206.

Aiken, L.H., Clarke, S.P., Sloane, D.M., Sochalski, J., Silber, J.H., 2002. Hospital nurse staffing and patient mortality, nurse burnout, and job dissatisfaction. JAMA 288 (16), 1987–1993.

Batty, M., 2001. Exploring isovist fields: space and shape in architectural and urban morphology. Environ. Plann. Plann. Des. 28 (1), 123–150.

Butt, S., Fredericks, T., Kumar, A., Wahl, J., Harrelson, K., Means, S., Dumasius, A., Brown, E., 2004. An evaluation of physiological work demands on registered nurses over a 12-hour shift. In: Proceedings of the XVIII Annual International Occupational Ergonomics and Safety Conference (ISOES). Houston, TX, USA.

Cai, H., Zimring, C., 2012. Out of Sight, Out of Reach: correlating spatial metrics of nurse station typology with nurses’ communication and co-awareness in an intensive care unit. In: Proceedings of the 8th International Space Syntax Symposium. Santiago, Chile.

Cama, R., 2009. Evidence-Based Healthcare Design, first ed. John Wiley & Sons, New Jersey.

Chaudhury, H., Mahmood, A., Valente, M., 2005. Advantages and disadvantages of single-versus multiple-occupancy rooms in acute care environments: a review and analysis of the literature. Environ. Behav. 37 (6), 760–786.

Chaudhury, H., Mahmood, A., Valente, M., 2006. Nurses’ perception of single-occupancy versus multi-occupancy rooms in acute care environments: an exploratory comparative assessment. Appl. Nurs. Res. 19 (3), 118–125.

Chaudhury, H., Mahmood, A., Valente, M., 2009. The effect of environmental design on reducing nursing errors and increasing efficiency in acute care settings: a review and analysis of the literature. Environ. Behav. 41 (6), 755–786.

Choi, K., Chai, C.G., Kwon, S.J., 2014. A Study on the Architectural Planning Guidelines of the Wards in Central Public Hospitals of the Communities, vol. 21. Korea Institute of Healthcare Architecture, pp. 15–26, 1.

Choi, K., Lee, H., Kim, C., Shin, Y.S., Jung, T.W., Kwon, S.J., 2017. A Study on the facility guidelines of the ward in hospitals. In: Proceedings of the Annual Conference of Korea Institute of Healthcare Architecture, B, pp. 13–20, 1.

Choudhary, R., Bafna, S., Heo, Y., Hendrich, A., Chow, M., 2010. A predictive model for computing the influence of space layouts on nurses’ movement in hospital units. J. Build. Perform. Simulat. 3 (3), 171–184.

Dijkstra, J., Timmermans, H., 2002. Towards a multi-agent model for visualizing simulated user behavior to support the assessment of design performance. Autom. ConStruct. 11 (2), 135–145.

Dym, C.L., Henchey, R.P., Delis, E.A., Gonick, S., 1988. A knowledge-based system for automated architectural code checking. Comput. Aided Des. 20 (3), 137–145.

Faller, M.S., Gates, M.G., Georges, J.M., Connelly, C.D., 2011. Work-related burnout, job satisfaction, intent to leave, and nurse-assessed quality of care among travel nurses. JONA: J. Nurs. Adm. 41 (2), 71–77.

Gurasco-Howard, L., Malloch, K., 2007. Centralized and decentralized nurse station design: an examination of caregiver communication, work activities, and technology. Health Environ. Res. Des. J. 1 (1), 44–57.

Hamilton, D.K., Shepley, M.M., 2010. Design for Critical Care: an Evidence-Based Approach. Elsevier/Architectural Press, Netherlands.

Health Resources and Services Administration, 2013. National Center for Health Workforce Analysis. Projecting the Supply and
Demand for Primary Care Practitioners through 2020. U.S. Department of Health and Human Services, Rockville, Maryland.

Helbing, D., Molnar, P., 1995. Social force model for pedestrian dynamics. Phys. Rev. 51 (5), 4282.

Helbing, D., Molnár, P., Farkas, I.J., Bolay, K., 2001. Self-organizing pedestrian movement. Environ. Plann. Plann. Des. 28 (3), 361–383.

Helbing, D., Farkas, I.J., Molnar, P., Vicsek, T., 2002. Simulation of pedestrian crowds in normal and evacuation situations. Pedestrian Evacuation Dynamics 21 (2), 21–58.

Hendrich, A., Chow, M., 2008. Healthcare Leadership: Maximizing the Impact of Nursing Care Quality: a Closer Look at the Hospital Work Environment and the Nurse’s Impact on Patient Care Quality. The Center for Health Design, pp. 1–21.

Hendrich, A., Chow, M.P., Skierzynski, B.A., Lu, Z., 2006. A 36-hospital time and motion study: how do medical-surgical nurses spend their time? Perm. J. 12, 25–34.

Heo, Y., Choudhary, R., Bafna, S., Hendrich, A., Chow, M.P., 2009. A modeling approach for estimating the impact of spatial configuration on nurses’ movement. In: Proceedings of the 7th International Space Syntax Symposium, vol. 1, p. 41, 1.

Hoogendoorn, S.P., Bovy, P.H., 2004. Pedestrian route-choice and activity scheduling theory and models. Transp. Res. Part B Methodol. 38 (2), 169–190.

Institute of Medicine, 2011. The Future of Nursing: Leading Change, Advancing Health. National Academies Press, Washington, DC.

Kim, M.Y., Chai, C.G., 2018. A study on the change of physical environment in Seoul Medical Center by providing comprehensive nursing service. Korea Ins. Healthc. Architect. J. 24 (1), 15–24.

Kobus, R.L., Skaggs, R.L., Bobrow, M., Thomas, J., Payette, T.M., Kliment, S.A., 2008. Building Type Basics for Healthcare Facilities, second ed. John Wiley & Sons, New Jersey.

Lee, J., 2019. Visibility and Circulation Efficiency in Hospital Nursing Units: Visibility and Accessibility Analysis Using Agent-Based Simulation (Doctoral dissertation). Yonsei University, Seoul, Republic of Korea.

Lee, J., Lee, H., 2020. Employing visibility and agent-based accessibility analysis to enhance social interactions in older adult care facilities. Architect. Sci. Rev. 1–11.

Lee, J.K., Eastman, C.M., Lee, J., Kannala, M., Jeong, Y.S., 2010. Computing walking distances within buildings using the universal circulation network. Environ. Plann. Plann. Des. 37 (4), 628–645.

Lu, Y., Zimring, C., 2012. Can intensive care staff see their patients? An improved visibility analysis methodology. Environ. Behav. 44 (6), 861–876.

Maben, J., 2009. Splendid isolation? The pros and cons of single adult care facilities. Architect. Sci. Rev. 1–11.

Mazurenko, O., Gupte, G., Shan, G., 2015. Analyzing US nurse turnover: are nurses leaving their jobs or the profession itself. J. Hosp. Adm. 4 (4), 48–56.

Ministry of Health and Welfare, 2018. The Tertiary Care Hospital List. Ministry of Health and Welfare. http://www.mohw.go.kr. (Accessed 1 January 2019).

Najian, A., Dean, D.J., 2017. Simulation of human wayfinding uncertainties: operationalizing a wandering disutility function. In: Advances in Geocomputation. Springer, Cham.

Nanda, U., Pati, S., Nejati, A., 2015. Field research and parametric analysis in a medical–surgical unit. Health Environ. Res. Des. J. 8 (4), 41–57.

National Health Insurance Service, 2019. Policy Direction of Comprehensive Nursing Care. Ministry of Health and Welfare. https://www.nhis.or.kr/ (Accessed 1 November 2019).

Nazarian, M., Price, A., Demian, P., Malekzadeh, M., 2018. Design lessons from the analysis of nurse journeys in a hospital ward. Health Environ. Res. Des. J. 11 (4), 116–129.

Orelana, N., Alsayed, K., 2013. On Spatial Wayfinding: agent and human navigation patterns in virtual and real worlds. In: Proceedings of the Ninth International Space Syntax Symposium. Sejong University, Seoul, p. 79.

Pati, D., Harvey, T., Cason, C., 2008. Inpatient unit flexibility: design characteristics of a successful flexible unit. Environ. Behav. 40 (2), 205–232.

Pati, D., Harvey, T., Thurstor, T., 2012. Estimating design impact on waste reduction: examining decentralized nursing. J. Nurs. Adm. 42, 513–518.

Pati, D., Harvey Jr., T.E., Redden, P., Summers, B., Pati, S., 2015. An empirical examination of the impacts of decentralized nursing unit design. Health Environ. Res. Des. J. 8 (2), 56–70.

Pennington, H., Isles, C., 2013. Should hospitals provide all patients with single rooms? BMJ 347, 5695.

Raubal, M., 2001a. Human wayfinding in unfamiliar buildings: a simulation with a cognizing agent. Cognit. Process. 2 (3), 363–388.

Raubal, M., 2001b. Ontology and epistemology for agent-based wayfinding simulation. Int. J. Geogr. Inf. Sci. 15 (7), 653–665.

Reynolds, C.W., 1987. Flocks, herds and schools: a distributed behavioral model. In: Proceedings of the 14th Annual Conference on Computer Graphics and Interactive Techniques, pp. 25–34.

Scott, A., Stevenson, T., Chua, V., 2012. Finance. The profitability of private patients. Health Serv. J. 122 (6322), 25.

Seo, H.B., Choi, Y.S., Zimring, C., 2011. Impact of hospital unit design for patient-centered care on nurses’ behavior. Environ. Behav. 43 (4), 443–468.

Shepley, M.M., Davies, K., 2003. Nursing unit configuration and its relationship to noise and nurse walking behavior: an AIDS/HIV unit case study. AJA Acad. J. 6, 12–14.

Shin, D., Kang, M., 2016. A study improving a nurse’s walking path and staff visibility in general hospital wards. J. Architect. Inst. Korea Plann. Des. 32 (1), 41–50.

Stephenson, J., 2015. Single rooms in hospitals “increase anxiety” among nursing staff. Nurs. Times 47.

Sturdavant, M., 1960. Comparisons of Intensive Nursing Service in a Circular and a Rectangular Unit: Rochester Methodist Hospital. American Hospital Association, Rochester, Minn (No.8).

Tao, H., Ellenbecker, C.H., Wang, Y., Li, Y., 2015. Examining perception of job satisfaction and intention to leave among ICU nurses in China. Int. J. Nurs. Sci. 2 (2), 140–148.

Thompson, D.R., Hamilton, D.K., Cadenehead, C.D., Swoboda, S.M., Schwindel, S.M., Anderson, D.C., Schmitz, E.Y., St Andre, A.C., Axon, D.C., Harrell, J.W., Harvey, M.A., Howard, A., Kaufman, D.C., Petersen, C., 2012. Guidelines for intensive care unit design. Crit. Care Med. 40 (5), 1586–1600.

Torrens, P.M., 2012. Moving agent pedestrians through space and time. Ann. Assoc. Am. Geogr. 102 (1), 35–66.

Trant, K., 2010. Ward design must not be restricted to single rooms. Nurs. Times 106 (26), 24.

Trites, D.K., Galbraith, F.D., Sturdavant, M., Leckwitz, J., 1970. The design of hospital unit design on the activities and subjective feelings of nursing personnel. Environ. Behav. 2 (3), 303–334.

Turner, A., 2007. From axial to road-centre lines: a new representation for space syntax and a new model of route choice for transport network analysis. Environ. Plann. Plann. Des. 34 (3), 539–555.

Turner, A., Penn, A., 2002. Encoding natural movement as an agent-based system: an investigation into human pedestrian behaviour in the built environment. Environ. Plann. Des. 29 (4), 473–490.

Ulrich, R., Zimring, C., Joseph, A., Choudhary, R., 2004. The Role of the Physical Environment in the Hospital of the 21st Century: a Once-In-a-Lifetime Opportunity. The Center for Health Design, Concord, CA.

Ulrich, R.R., Zimring, C., Zhu, X., DuBose, J., Seo, H.B., Choi, Y.S., Quan, X., Joseph, A., 2008. A review of the research literature on evidence-based healthcare design. Health Environ. Res. Des. J. 1 (3), 61–125.
The spatial arrangement of patient rooms for minimum nurse travel

van Oostveen, C.J., Braaksma, A., Vermeulen, H., 2014. Developing and testing a computerized decision support system for nurse-to-patient assignment: a multimethod study. Comput. Inf. Nurs. 32 (6), 276–285.

Vizzari, G., Manenti, L., Ohtsuka, K., Shimura, K., 2015. An agent-based pedestrian and group dynamics model applied to experimental and real-world scenarios. J. Intell. Transport. Syst. 19 (1), 32–45.

Wagenaar, C., Mens, N., 2018. Hospitals: a Design Manual. Birkhäuser, Berlin, Germany.

Wang, P., 2019. PedSim. Available online at: https://www.food4rhino.com/app/pedsim. (Accessed 17 March 2019).

Witkoski, A., Dickson, V.V., 2010. Hospital staff nurses’ work hours, meal periods, and rest breaks: a review from an occupational health nurse perspective. AAOHN J. 58 (11), 489–497.

Yang, Y., Roux, A.V.D., Auchincloss, A.H., Rodriguez, D.A., Brown, D.G., 2011. A spatial agent-based model for the simulation of adults’ daily walking within a city. Am. J. Prev. Med. 40 (3), 353–361.

Yi, L., Seo, H.B., 2012. The effect of hospital unit layout on nurse walking behavior. Health Environ. Res. Des. J. 6 (1), 66–82.

Zborowsky, T., Bunker-Hellmich, L., Morelli, A., O’Neill, M., 2010. Centralized vs. decentralized nurse stations: effects on nurses’ functional use of space and work environment. Health Environ. Res. Des. J. 3 (4), 19–42.

Zimring, C., Joseph, A., Choudhary, R., 2004. The Role of the Physical Environment in the Hospital of the 21st Century: A Once-In-a-Lifetime Opportunity. The Center for Health Design, Concord, CA.