AGENT-DRIVEN ACCESSIBILITY AND VISIBILITY ANALYSIS IN NURSING UNITS

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Abstract. This study investigates the nursing unit design for care quality and efficient operation, evaluating visibility and walking distance of nurses in the different form of layout. Sufficient visibility from nurses’ station to patient rooms and corridors can increase nurses’ care abilities to understand the needs and movements of patients. The workload and time caused by nurse’s walking can be diverted to patient care. Isovist analysis and agent-based simulation are experimented to investigate the effects of spatial layout on visibility and nurses’ accessibility to patients. In the isovist analysis, the nurses’ station facing patient rooms were more effective in nurse-to-patient visibility. In the nurse’s walking trail analysis, uneven walking distance of each nurse appeared due to the asymmetric patient room layout centering the nurses’ station and heavy room allocation plan. Understanding the potential impacts of design parameters enables designers to predict possible behaviors in each design alternative and to make effective and efficient design decisions for the occupants. This study underlines the role of the physical environment in the delivery of patient care and nurse’s well-being. It presents an evaluation framework integrating syntactic analysis and agent-based simulation to predict the effect of the spatial layouts on the hospital activities.

Keywords. Nursing unit design; Isovists; Agent-based modeling; Accessibility; Visibility.

1. Introduction

Physical layouts that enable close access between patients and nurses continue to be essential considerations in hospital design for staff function and patient care quality. Patient experience and satisfaction is a crucial part of the quality of healthcare services (the Institute of Medicine 2001). Nurses’ roles and responsibilities are significantly important to meet the increased demand for patient care quality to advance patients’ improvements (the Institute of Medicine 2011). As healthcare and technology evolved over centuries, so did the role and form of the nursing units. The planners have tried various layout configurations to increase the effectiveness and efficiency in hospital activities in the development of the forms of the nursing units. The more compact and concentric plans have been established with groupings of support areas, however, still labor-intensive to
nurses due to their excessive size. The long walking distances and heavy workload of nurses continue to be issued.

This paper investigates how the nursing unit design effects visibility and walking distances of nurses. The isovist analysis evaluates the visibility from the nurses’ station to the patient rooms. The agent-based modeling simulates and evaluates nurses’ walking trails. This study focuses to evaluate nurse-to-patient accessibility for care quality and efficient operation. The isovist analysis has been employed for syntactic measures of visibility. The agent-based modeling has been applied for pedestrian walk simulation in Rhino model space using Grasshopper. Agent-based modeling allows a differentiated approach of measuring walking distances being closer to the people’s movement patterns in real life. This study presents an evaluation framework integrating syntactic analysis and agent-based simulation to predict the effect of different layouts on visibility and occupants’ movement patterns.

2. Visibility from Nurses’ Station

Visibility from the nurses’ station has been an important design measure for the quality of patient care. Sufficient visibility to patient rooms and corridors can increase nurses’ care abilities to understand and predict the needs and movements of patients. Sturdavant and colleagues (Trites et al. 1969; Trites et al. 1970) compared the behavioral and perceptual influence of three types of nursing unit design - four of radial units, four of double-corridor units, and four of single-corridor units. The literature suggests that the layout of nursing units affects nurses’ behavior, walking distances and patients’ perceived quality of care. Several studies have reported that dense radial layouts can be beneficial for shorter nurses’ walking distances, patient monitoring, reducing nursing workload, and improved patient satisfaction (Shepley and Davies 2003; Sturdavant 1960; Trites et al. 1970). These studies also suggested that improved patient visibility and observation helps to achieve better performance outcomes. The improved visibility reduced walking for nurses (Hendrich et al. 2002; Lu 2010; Lu and Zimring 2012), which translates into more time in patient care (Lu and Zimring 2012), as well as reducing falls and injuries (Hendrich et al. 2002; Pati et al. 2008). Literature has shown the patients’ satisfaction and perceived quality of care was higher in units with better visibility which increased contact and communication with patients (Trites et al. 1969; Trites et al. 1970). With the central nursing desk with more patients being visible from, direct observation was allowed and the ability to care for patients improved (Kobus et al. 2008). In this study, the visibility from the nurses’ station in triangular units has been evaluated, how they face patient rooms in relation to their different forms and locations.

3. Nurse Walking Distance

The typical double-loaded corridor was the standard design for many years because of the need for cross-ventilation and natural lighting. However, it made very long distances between the nurses' station and the end rooms of the unit. Nurses’ walking distance is another crucial part in layout planning as many units are built
in excessive size and therefore labor-intensive. Reducing unnecessary movement of nurses to optimize nurses’ movement is essential. Literature has shown that the nurses who consumed more time in walking spent less time at the patients’ bedsides (Trites et al. 1970; Ulrich et al. 2004; Hendrich et al. 2008). Hendrich, Chow, Skierczynski, and Lu (2008) found that nurses walked an average of 3.0 to 5.5 km in the day shift; while for the night shift nurse, the average walking distance varied between 2 and 5 km. Nurses’ walking distance can be as much as 10 km during a shift (Pati et al. 2012). Researchers tried to evaluate how much walking distance can be shortened and how much time can be saved from wasteful walking which can be directed toward patient direct care and nurse well-being. From this point of view, the more compact and concentric plans have been established with groupings of concentric support areas. Still, the long walking distances of nurses in large facilities are being issued and planners are trying to develop effective layout configurations to increase effectiveness and efficiency in nurses’ movement patterns in inpatient care unit design.

4. Method

4.1. ISOVIST ANALYSIS

An isovist is a set of all points visible from a particular selected vantage point in a given space (Benedikt 1979). To examine the properties of nurse-to-patient visual experiences in different unit configurations in relates to nurses’ desk type and location, the isovist analysis is conducted at the locations of the nurses’ station of each sample case. As developing isovist properties for each case, isovist area measures and the number of patient rooms being visible are counted for comparison. The isovists are measured at eye level, and furniture (including nurses’ station), low partitions and doors are removed from the layout for measurement.

4.2. AGENT-BASED MODELING

The agent-based simulation is adopted to model nurses’ movement patterns through virtual agent simulation. The agent-based simulation tool is used to evaluate nurses’ walking distances and movement patterns on the sample plans. Grasshopper plug-in, ‘PedSim’ is used for modeling pedestrian walking behavior in Rhino space. The pedestrian walking behavior is defined by a series of Grasshopper components, setting agent target points, vision properties, target force etc. ‘PedSim’ is based on the social force model (Helbing and Molnar 1995) with the collision avoidance model. Agents choose the shortest route, avoid collisions with other objects by analyzing the current environment, and move to the target points. An agent, which is a nurse in this simulation, travels from a starting point - nurses’ station, to a destination point - patient rooms allocated for each nurse, avoiding obstacles - walls and furniture in the layout. The simulation process is: 1) the agent finds the shortest path to the destination point, 2) it visits interest points when it sees them avoiding obstacles and other agents, 3) it goes to the destination point.
For nurses’ walking distance calculation, one rounding path of each nurse is set for the simulation. A nurse visits the preparation room and goes to each of the allocated patient room, and re-routes to its destination point, the nurses’ station for charting. In Grasshopper, the simulation process is set plugging in groups of inputs and outputs into the engine component. Inputs include the start points, destination points, interest points, person template, and obstacle geometry as shown in Figure 2. The person template is set for agents’ movement behavior by vision angle and target force. In this study, agents move with vision angle of 170 degrees. Outputs are the agent positions, trails of agents and the total distance of agent trails. A Boolean toggle and a timer control the start and the loop.

For tracing the accumulated walking trails of nurses, the setting is based on the three shifts of nurses for the day, evening and night, and three times of nurses’ ward rounding of care during each shift. Each rounding is for oral medication, injection and vital sign checking. Additional visits can be optional but are not counted in this study.

![Figure 1. Simulation view of agent walking trails in Rhino model space.](image1)

![Figure 2. Setting parameter values of agent behavior in Grasshopper.](image2)
4.3. CASE DESCRIPTION

Since 2000, various shapes of layouts are being built in Korea. Among them, the rectangular shape unit with racetrack type corridor and triangular shape unit with double corridor are being the most adopted unit shapes. In this study, three triangular shape unit plans with double corridor are examined. The sample cases are built after 2005 with a capacity of more than 80 beds on one floor. Each floor is divided into two nursing units and in each unit, 10 to 14 patients are allocated for one nurse in a shift, which causes heavy workload to nurses.

Unit A is built in 2000 and it has two double-bed rooms and ten four-bed rooms. There are 12 patient rooms with 42 beds in total. One nurse in a shift takes care of 10 to 12 patients of three rooms. The nurses’ station is a centralized type with one main station located at the center corner of the layout. The nursing support rooms are located behind the nurses’ station. Unit B has 12 patient rooms of single, double, four and five beds with 42 beds in total. One nurse takes care of 14 patients of three or four patient rooms; one room of single or double beds, and two or three rooms of four or five beds. Therefore, the workload is heavier than in other cases. The nurses’ station is a centralized type with two stations being located back to back in the middle of nursing support space. Unit C has 17 patient rooms of single, double, and five beds and 42 beds in total. One nurse per shift takes care of 10 to 12 patients of two to eight rooms. The nurses’ station is a centralized type with one main and one secondary station with the support rooms centrally located. The main nurses’ station is located near the elevator core and secondary station is located at the end corner of the other side.

<table>
<thead>
<tr>
<th>Unit Type</th>
<th>Year Completed</th>
<th>Unit Shape</th>
<th>Corridor Type</th>
<th>Total Beds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit A</td>
<td>2000</td>
<td>Triangle</td>
<td>Double</td>
<td>42</td>
</tr>
<tr>
<td>Unit B</td>
<td>2005</td>
<td>Triangle</td>
<td>Double</td>
<td>42</td>
</tr>
<tr>
<td>Unit C</td>
<td>2008</td>
<td>Triangle</td>
<td>Double</td>
<td>42</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Room Type</th>
<th>1 Bed</th>
<th>2 Bed</th>
<th>4 Bed</th>
<th>5 Bed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit A</td>
<td>2 (4)</td>
<td></td>
<td>10 (40)</td>
<td></td>
<td>12 (42)</td>
</tr>
<tr>
<td>Unit B</td>
<td></td>
<td>2 (4)</td>
<td>4 (16)</td>
<td>4 (20)</td>
<td>12 (42)</td>
</tr>
<tr>
<td>Unit C</td>
<td>7 (7)</td>
<td>5 (10)</td>
<td></td>
<td>5 (25)</td>
<td>17 (42)</td>
</tr>
</tbody>
</table>
5. Result

5.1. ISOVIST ANALYSIS

The isovist properties are measured from the locations of the nurses’ station for each case. The isovist area sizes are shown in Table 3 and the isovist maps are presented in Figure 3. Unit A has one central nurses’ station and Unit B and Unit C has two in separate. In Unit A and Unit B, the nurses’ stations are centrally located and in Unit C two stations are located in the opposite ends. In Unit A and Unit B, a large volume of visible points is facing towards the patient rooms. Nine out of twelve patient rooms are directly visible from the nurses’ station in Unit A and Unit B. In Unit C, only nine out of seventeen patient rooms are visible even though the largest number of isovist area size is measured. It is because the nurses’ station in Unit C is facing the elevator hall rather than the patient rooms. The nurse-to-patient visibility is more effective when the nurses’ station is facing the patient rooms. Unit A is most efficient in nurse-to-patient visibility among three cases, considering Unit A has only one nurses’ station. For the nurses’ station, the center corner in the middle of the room layout is more effective for high nurse-to-patient visibility in triangularly shaped plans.

<table>
<thead>
<tr>
<th></th>
<th>Unit A</th>
<th>Unit B</th>
<th>Unit C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isovist Area (m²)</td>
<td>181.662</td>
<td>155.061 - 191.595</td>
<td>89.200 - 206.209</td>
</tr>
</tbody>
</table>

Table 3. Isovists generated from nurses’ station locations.

![Figure 3. Isovist maps from nurses’ station locations of each unit.](image)

5.2. NURSES’ WALKING DISTANCES

The walking trail of one rounding of each nurse is simulated and the walking distance is counted. The result is shown in Table 4 and the trails are presented in Figure 4. Starting at the nurses’ station, visiting the preparation room, moving to assigned patient rooms, and coming back to the nurses’ station for charting is counted as one nurse’s walking path for each rounding. The nurse-patient room assignments are marked on the floor plans in Figure 4. The number of patients for each nurse is to be similar in the plans. Normally single or double-bed patient
rooms and multi-bed patient rooms are allocated together for each nurse to tune the workload. Also, the adjacent rooms are to be assigned as much as possible. The distance to the patient room doors are counted and the movements in the patient rooms are not included in this study.

Even though Unit A has only one nurses’ station, total walking distance and average walking distance are the shortest among the three cases. However, Nurse 4 of Unit A has a long linear walking trace comparing to other nurses. It is due to the asymmetric room layout centering the nurses’ station, which causes uneven walking distances between nurses. In all three cases, the difference in walking distance of each nurse is about double in length. In Unit C the longest nurse walking trace is 2.5 times longer than the shortest walking trace. Also, Nurse 1 of Unit B has the longest walking distance among all nurses and the average walking distance of Unit B is the longest, therefore heavy workload to the nurses is assumed. In Unit B and Unit C, the advantages of positioning two nurses' stations are not reflected effectively in shortening the walking distances. It is because the nurses are caring patients in both north and south rooms. It is estimated to be more effective for nurses to care rooms on one side as seen in Unit A to shorten nurses’ walking distances.

| Table 4. Nurses’ walking distance (m) for one rounding of the assigned patient rooms. |
|-----------------------------------------------|----------------|----------------|----------------|----------------|----------------|---------------|
| Unit A | Nurse 1 | 32.91 | Nurse 2 | 41.84 | Nurse 3 | 38.13 | Nurse 4 | 67.34 | Average | 45.06 | Total | 180.22 |
| Unit B | 84.79 | 61.58 | 48.73 | 65.03 | 195.10 |  |
| Unit C | 62.79 | 59.35 | 30.88 | 75.75 | 57.19 | 228.77 |

Figure 4. Nurses’ walking trails for one rounding to the assigned patient rooms from the nurses’ station.

5.3. NURSES’ WALKING TRAILS
The accumulated walking trails present circulation patterns and movement density occurring on the corridors. The nurses’ walking traces are simulated based on
nurses’ rounding paths; three roundings per shift and three shifts per day. In Unit A, nurses’ walking paths are well distributed into four sections of the unit. Nurse 1, 2 and 3 of Unit A walk relatively short distances around the nurses’ station and heavy density of traces don’t appear on the plan. In Unit B, a central corridor in the support area is not used as much as expected for nurses’ circulation. The traces are more accumulated on the corridors in front of the patient rooms. The corridor penetrating the support area is used as preparation space and only Nurse 3 takes it for the shortest path. In Unit C, the back area of the main nurses’ station is being used for circulation as a shortest path and this might cause heavy density around the area. The center corridor in the middle of the support rooms is quite helpful for circulation efficiency shortening the paths of Nurse 1 and 2.

Figure 5. Accumulated walking trails of nurses to the assigned patient rooms from nursing station.

6. Conclusion

This study explored the impact of spatial configuration on nurse-to-patient visibility and accessibility in the inpatient nursing units for care quality and efficient operation. It integrated the syntactic method and parametric modeling to investigate the effects of spatial configuration on visibility and occupants’ movement patterns. The isovist analysis evaluated the visibility from the nurses’ stations to the patient rooms, and the agent-based modeling evaluated nurses’ walking trails. In the isovist analysis, the nurses’ stations facing patient rooms
were more effective in nurse-to-patient visibility. In nurses’ walking trail analysis, all corridors and rooms were well covered by nurses’ movements yet the difference in walking distance by each nurse was measured. Longer walking distance appeared due to asymmetric room layout or uneven room allocation plans, which might cause more workload and less time on patients’ bedside to the assigned nurses.

Understanding the potential impacts of design parameters enables designers to predict possible behaviors in each design alternative and to make effective and efficient design decisions for the occupants. This study underlines the role of the physical environment in the delivery of patient care and nurse’s well-being. It presents an evaluation framework integrating syntactic analysis and agent-based simulation to predict the effect of the spatial layouts on the hospital activities. To increase the efficiency and effectiveness of nursing care in hospital function and delivery of patient care, finding the optimized unit shapes and room allocation plans will be further investigated in more case studies.

Acknowledgement

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References

Benedikt, M. L.: 1979, To take hold of space: isovists and isovist fields, Environment and Planning B: Planning and design, 6(1), 47-65.
Institute of Medicine, : 2011, The future of nursing: Leading change, advancing health, National Academies Press, Washington, DC.
