Physical and Visual Accessibilities in Intensive Care Units: A Comparative Study of Open-Plan and Racetrack Units

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Abstract

This study compared physical and visual accessibilities and their associations with staff perception and interaction behaviors in two intensive care units (ICUs) with open-plan and racetrack layouts. For the study, physical and visual accessibilities were measured using the spatial analysis techniques of Space Syntax. Data on staff perception were collected from 81 clinicians using a questionnaire survey. The locations of 2233 interactions, and the location and length of another 339 interactions in these units were collected using systematic field observation techniques. According to the study, physical and visual accessibilities were different in the two ICUs, and clinicians' primary workspaces were physically and visually more accessible in the open-plan ICU. Clinicians with physically and visually more accessible primary workspaces indicated that they knew their peers and where their peers were located in these units. The physical and visual accessibilities of clinicians' primary workplaces also affected their perception of interaction and communication and of teamwork and collaboration in these units. Physical and visual accessibilities showed significant positive associations with interaction behaviors in these units, with the open-plan ICU showing stronger associations. However, physical accessibilities were less important than visual accessibilities for explaining the variations in interaction behaviors in these ICUs. The implications of these findings for ICU design are discussed.

Keywords: Intensive care unit; Physical and visual accessibilities; Open-plan layout; Racetrack layout; Clinicians' perception; Interaction and communication; Teamwork and collaboration

Introduction

Physical and visual accessibilities in ICUs

Physical and visual accessibilities are determined based on the physical and visual connectedness of the spaces in an environment. Though recent developments in monitoring devices have eliminated some need for direct patient monitoring, clinicians' need for better physical and visual accessibilities remains important in intensive care units (ICUs). This is indicated by the fact that while diagnosis may be done well using either proximate or remote monitoring devices, proper medical care must depend on how physically and visually accessible people, spaces, medication and supplies, and furniture, fixtures and equipment are in ICUs.

Since the publication of the Nuffield Report in the 1950s [1], several empirical studies have confirmed many behavioral and psychological benefits of physical and visual accessibilities in hospital nursing units in general and ICUs in particular concerning the delivery of patient care. Rashid [2] provides an integrative review of the literature. For example, getting medication and supplies to the patient room may be difficult if medication and/or supply rooms are not easily accessible. Nursing staff may need to walk more and spend more time walking in a unit with poor physical and visual accessibilities. In contrast, a unit with better physical and visual accessibilities may help reduce walking, may allow better time utilization and may make staff more satisfied. When the conditions of a patient deteriorate unexpectedly, clinicians may not get the help they need from others in an ICU with poor physical and visual accessibilities. Teamwork and collaboration among large medical teams may not occur or may be negatively affected if supportive spaces are not easily accessible in ICUs.

Even concerning diagnosis using monitoring devices, one cannot rule out the importance of clinicians' need for better physical and visual accessibilities in ICUs. This is indicated by the fact that these

environmental characteristics can help reduce cognitive loads resulting from the complexity of the monitoring task itself. For example, some anesthesia monitors in ICUs can display as many as 36 critical pathologic patient parameters—often in real time, and visualizing these variables through numerical data and waveforms can be a demanding cognitive task [3]. Finding easy and fast ways to interpret these parameters may help reduce ICU nurses' cognitive loads and errors resulting from these loads [4]. In the absence of proper monitors that may also work as cognitive aids [5], better physical and visual accessibilities to colleagues who can help make sense of monitoring data may still be the best option available for nurses to become productive with less error.

Clinicians' need for better physical and visual accessibilities in ICUs is further indicated by the fact that these environmental characteristics can help facilitate critical clinical decision-making that cannot depend solely on the data from monitoring devices given the complex and heterogeneous nature of the physiology and pathophysiology of a critically ill patient. While the fast evolution of computing power and informatics may make it possible to use the data from these monitors in clinical decision support systems, so far such decision support systems remain absent [6]. As a result, the direct examination of a patient supported by monitoring data may still be the most useful way to assess and evaluate the status of a patient for clinical decisions and care.

More importantly, however, physical and visual accessibilities in ICUs have shown to affect patient outcomes. For example, Leaf *et al.* [7] reported that severely ill patients may experience higher mortality rates when assigned to poorly visible ICU rooms (rooms that are not visible from central nurse station). Recently, Lu *et al.* [8] reanalyzed the data used in the study reported by Leaf *et al.* [7] using rigorous measures of the visibility of patient rooms, and found that among the sickest patients (those with Acute Physiology and Chronic Health Evaluation II > 30), the visibility of patient rooms accounted for 33.5% of the variance in ICU mortality (p = 0.049), thus providing additional support for the importance of visual accessibility in relation to patient outcomes.

Given the importance of physical and visual accessibilities in ICUs, the 1995 *ICU Design Guidelines* [9] state,

> "Bedside monitoring equipment should be located to permit easy access and viewing, and should not interfere with the visualization of or access to the patient. The bedside nurse and/or monitor technician must be able to observe the monitored status of each patient at a glance. This goal can be achieved either by a central monitoring station, or by bedside monitors that permit the observation of more than one patient simultaneously. *It should be noted that neither of these methods are intended to replace bedside observation*. [9, p.7; italics added]

Likewise, the *2010 FGI guidelines* state,

> There *shall* be direct or remote visual observation between the administrative center, nurse station, or staffed charting stations and all patient beds in the critical care unit. Such observation *shall* provide a view of the patient while the patient is in bed. [10, p. 101; italics added]

Physical and visual accessibilities versus privacy and natural light in ICUs

Despite the importance of better physical and visual accessibilities in ICUs, recent reviews show that almost all award-winning best practice example ICUs built between 1993 and 2012 have private patient rooms only [11-13]. This is important because private rooms are a permanent environmental mechanism to control physical and visual accessibilities in ICUs. Emphasizing the importance of private patient rooms, the more recent *2012 ICU guidelines* [14] state,

> Research has demonstrated that single rooms are superior to multi-bed rooms in terms of patient safety. They also enhance privacy. Rooms providing full enclosure have been shown to increase sleep quality…To protect patient privacy, room design that limits obtrusive sightlines during care or procedures is desirable. Windows between rooms may compromise privacy. To address this

problem, various window designs permit selective viewing by staff while nonetheless protecting patient privacy. [14, p. 1588, 1596]

In contrast, regarding physical and visual accessibilities the*2012 ICU guidelines* state, "Whether a centralized or decentralized design is chosen, caregivers must be able to observe patients from many points within the unit…Certain clinical support functions meet immediate or emergency needs. For these, it is critical to consider both proximity to patients and ease of access for staff" [14, p. 1588, 1591]. In its tenor and content, this statement puts less emphasis on physical and visual accessibilities than that provided in the 1995 *ICU Design Guidelines*.

Along with privacy, the *2012 ICU guidelines* also emphasize the need for natural light and outside view:

> Natural light is essential to the wellbeing of patients and staff, and is required by most codes. Each patient care space should provide visual access to the outdoors, other than skylights, with not less than one window of appropriate size per patient bed area…Providing patients an outside view – preferably overlooking a garden, courtyard, or other natural setting – may help relieve anxiety and stress, improve care, enhance patients' comfort, and improve patient orientation. In cases where a patient's bed must face the interior of the unit to permit close observation by staff, an adjustable mirror mounted on the wall or ceiling may provide the patient a view of the outdoors. [14, p. 1589]

A similar emphasis on the need for natural light and outside view in the patient room is also found in the *2010 FGI guidelines*:

> Each patient bed *shall* be provided with natural light by means of a window(s)… If a multiple-bed room with patient cubicles is provided, there *shall* be no more than one intervening patient cubicle between any patient bed and the window(s)… Distance from the patient bed to the window *shall* not exceed 50 feet (15.24 meters). [10, p. 100; italics added]

As private rooms with natural light and outside view in ICUs become the norm in the United States, open-plan ICUs with no permanent separation between patient beds (**Figure 1**) are being phased out. In its place, racetrack ICUs, commonly defined as a unit having a circulation ring separating patient rooms around the perimeter from a service core in the center with nursing station and other support and service functions (**Figure 1**), are becoming common. For ICU design, our recent emphasis on the need for privacy, natural light, and outside view has almost made it certain that a racetrack layout is given appropriate consideration for ICUs. Therefore, it is no surprise that between 1993 and 2012, the racetrack type layout has been the most prevalent type of ICU layout, accounting for 73.33% of all award-winning best practice example ICUs built in the USA and Canada [11-13].

Study Hypotheses

As we highlight the basic differences between open-plan and racetrack ICUs, it should be noted that guesswork may not work well when we consider physical and visual accessibilities in ICUs with different layouts. Even though it is commonly understood that open-plans ICUs are physically and visually more accessible than racetrack ICUs, many environmental and technological requirements of ICUs may render this common understanding wrong. This, of course, makes it very difficult to know how physical and visual accessibilities in open-plan and racetrack ICUs may affect staff perception and behavior related to patient care. Therefore, to learn more about physical and visual accessibilities in open-plan and racetrack ICUs and how they may be associated with staff perception and behaviors in ICUs, we test the following hypotheses in this study:

> Hypothesis 1: *Overall, open-plan ICUs will be physically and visually more accessible than racetrack ICUs*.

> Hypothesis 2: *The primary workspaces of clinicians in open-plan ICUs will be physically and visually more accessible than those in racetrack ICUs*.

Hypothesis 3: *Most clinicians will know their peers in ICUs, but physical and visual accessibilities of ICU clinicians' primary workspaces will affect how well they know their peers.*

Hypothesis 4: *Physical and visual accessibilities of ICU clinicians' primary workspaces will affect how well they know where others are located in the unit.*

Hypothesis 5: *Physical and visual accessibilities of ICU clinicians' primary workspaces will affect their perception of how well a unit supports interaction and communication.*

Hypothesis 6: *Physical and visual accessibilities of ICU clinicians' primary workspaces will affect their perception of how well a unit supports teamwork and collaboration.*

Hypothesis 7: *Physical and visual accessibilities of ICU will affect the frequency and length of interactions in ICUs.*

Methods

After obtaining approvals from the Institutional Review Boards (IRB) of all the involved institutions, this study was conducted in two ICUs – one 32-bed open-plan unit and another 28-bed racetrack unit (**Figure 1**) – of a university teaching hospital to test the hypotheses stated above. These units serving adult patients are located next to each other on the same floor of the hospital. Regarding our study interests, it should be noted that the ratio of patient to nurse and the clinical model in both units were similar; and so were the technologies available in these units for interaction and communication and for teamwork and collaboration at the time of study.

For the study, three sets of data were collected from each unit. The data on physical and visual accessibilities were collected using the techniques of spatial analysis of Space Syntax. The data on staff perception were collected using a questionnaire survey. Finally, the data on interaction frequency and

length were collected using systematic behavioral observation protocols. These data collection methods are discussed next.

Space Syntax analysis

To test Hypotheses 1 and 2, the spatial analysis techniques of Space Syntax were used. They help characterize physical and visual accessibilities in the spatial layouts of buildings and cities using various rigorously defined measures [15, 16]. These measures have shown significant associations with spatial behaviors and perception in hospital units in previous studies [17-23]. In one of these studies, Hendrich e*t al.* [18] investigated the correlations between the physical and visual accessibilities of individual spaces and the radio-frequency identification (RFID) data on the movement patterns of 53 nurses covering 143 nursing shifts from 5 medical-surgical units, and found that as the physical and visual accessibilities of patient rooms increased, so did the frequency of shorter visits to these rooms and the total amount of time spent in these rooms. In another, Cai and Zimring [17] found strong correlations between the physical and visual accessibilities of spaces and the frequency of nurses' interaction and peer awareness in these spaces in two different wings of a neurological ICU. In yet other studies, Lu et al. [19, 20] found that clinicians are tuned to different aspects of physical and visual accessibilities based on their roles in ICUs.

Also using Space Syntax techniques, Rashid *et al.* [21] recently reported a study describing four interaction-related behaviors among three groups of users in relation to physical and visual accessibilities of spaces in four ICUs of different size, geometry, and specialty. Despite significant differences in unit characteristics and interaction-related behaviors, the study found that when nurses and physicians "interact while sitting" they prefer spaces that help maintain a high level of environmental awareness; that when nurses "walk" and "interact while walking" they avoid spaces with better global physical and visual accessibilities; and that everyone in ICUs "walk" more in spaces with higher control over neighboring spaces in terms of physical and visual accessibilities. Based on the findings, the authors argue that the observed consistent behavioral patterns might have occurred due to the similarities in the physical and

visual accessibilities of different categories of spaces in the units over and above their more general functional similarities.

Additionally, Space Syntax techniques have also been used to study the association of physical and visual accessibilities with patients' and families' privacy in hospital units. For example, in a study reported by Alalouch and Aspinall [22], a group of 79 subjects were asked to complete a questionnaire on privacy and to select preferred and disliked locations on the plans of different types of nursing units. In the study, participants' chosen locations for privacy showed a systematic relationship with the physical and visual accessibilities of the unit layouts. In a follow-up study, Alalouch *et al.* [23] investigated the effect of age, gender, previous experience of space and cultural background on people's chosen spatial location for privacy defined based on physical and visual accessibilities. Findings indicated a universal preference for spatial location of privacy across culture, age and gender, and a specific significant difference for spatial location of privacy because of previous spatial experience.

In this study therefore various measures derived using the axial map and visibility graph analyses of Space Syntax were used to describe the physical and visual accessibilities of the ICUs. For our purpose, it is important to note here that the axial map analysis emphasizes physical accessibility and the visibility graph analysis emphasizes visual accessibility in a spatial layout. For the axial map analysis, the layout of an environment is reduced to a fewest set of axial lines covering all routes of movements and circulation rings in the layouts. Various measures describing the physical accessibility of an axial line are then computed based on how the line was connected to the other lines in the map [16]. For the visibility graph analysis (VGA), the layout of an environment is divided into a cellular grid. Various measures describing the visual accessibility of a cell are then computed based on how the visual field of the cell was interconnected with the visual fields of the other cells in the grid [24]. The *Depthmap* software [25] is used in this study to perform both the analyses.

Space Syntax uses graphs to compute the physical and visual accessibilities measures of a layout. In a graph, the axial lines of the axial map or the visual fields of the cells of a grid defining the layout are treated as vertices or nodes and their intersections or connections as edges. In order to represent how a line is connected to all the other lines or a visual field is connected to all the visual fields in the layout, this graph can be rearranged using a line or a cell as the root vertex and all the other lines or cells as vertices on successive layers defined based on the minimum number of lines or visual fields one must use to reach them from the given line or cell. The rearranged graph, also known as the justified-graph, will have few layers if the line or cell is well connected to other lines or spaces, or it will have more layers if the line or space is poorly connected to other lines or spaces. **Figure 2** illustrates the process using the axial map analysis as an example. Space syntax then describes the relational or network properties of the graph and its vertices using various graph-theoretic measures. Among the many graph-theoretic measures Space Syntax uses, the following ones are used in this study describing the physical and visual accessibilities of a layout:

1. *Connectivity*: The connectivity value of a node in a graph defines how well the node is physically or visually accessible from its neighboring nodes in the graph. To put simply, it is the number of lines directly intersecting a given line, or the number of visual fields overlapping the visual field of a given cell. Therefore, *connectivity* describes accessibility at the line or cell level of a spatial system.

2. *Integration at Radius-3*: The integration value at radius-3 of a node in a graph defines how well the node is physically or visually accessible from all the other nodes at 3 steps away from the given node in the graph. It is an algebraic function of the mean depth (MD) value of the node, which is the sum of the shortest distances between the node and all other nodes at 3 steps away in the graph divided by the total number of nodes at 3 steps away from the node less 1. Therefore, *integration R3* describes accessibility at the subsystem level of a spatial system.

3. *Integration at Radius-n*: The integration value at radius-n of a node in a graph defines how well the node is physically or visually accessible from all the other nodes at *n* steps away from the given node

in the graph. It is an algebraic function of the mean depth (MD) value of the node, which is the sum of the shortest distances between the node and all other nodes at n steps away in the graph divided by the total number of nodes in the graph less 1. Therefore, *integration Rn* describes accessibility at the level of a spatial system.

Altogether, the study uses three axial map measures—axial connectivity, axial integration R3 and axial integration Rn—describing physical accessibilities; and three visibility graph measures—visual connectivity, visual integration R3 and visual integration Rn—describing visual accessibilities at the line/cell, subsystem and system levels. For illustrative purposes, **Figure 3** shows the axial map of one of the ICUs colored using axial integration-Rn, and **Figure 4** shows the cellular grid of one of the ICUs colored using visual integration-Rn.

Questionnaire survey

To collect data on staff perception, we conducted a questionnaire survey. Full-time and part-time ICU nurses on all shifts, physicians and intensivists who were salaried and associated with the unit, residents (where applicable), and attending physicians were invited to complete the questionnaires. Participation in the study was voluntary. Participants were recruited through emails or were approached in person. The IRB-required information and cover sheets were attached to the questionnaire to ensure that participants fully understood the intent of the study and the consequences of their participation.

The questionnaire included the following questions pertaining to Hypotheses 3 to 6:

1. Do you know the names of other clinicians working on the unit? (Y/N) – indicating if a participant knows her peers in the units for Hypothesis 3
2. Do you know the location of other clinicians working on the unit? (Y/N) – indicating if a participant knows where her peers are located in the units for Hypothesis 4

3. Do you think interaction and communication is better when peers are located close within sight? (Y/N) – indicating whether or not physical and visual accessibilities are important for a participant in relation to interaction and communication for Hypothesis 5

4. Do you think unit provides better opportunities for teamwork and collaboration? (Y/N) – indicating whether or not a unit provides teamwork and collaboration opportunities for Hypothesis 6

The survey questionnaire also included a plan for a participant to show her primary work location in the ICU. Later, the physical and visual accessibilities of each location were measured using axial and visual connectivity, integration-R3 and integration-Rn, as described in the previous subsection.

81 valid responses were received from the two units, 34 from the open unit and 47 from the racetrack unit. **Table 1** shows the distribution of survey participants based job types. Note that the majority of survey participants were nurses working in the two units.

Behavioral observations

To test Hypothesis 7, systematic field observations of interactions were conducted in each of the two ICUs. Interaction was defined as an event where individuals would actively engage with other individual/s in any activity for any measurable amount of time. Examples of these activities include talking to each other, looking at an image or a chart together with or without talking, attending a patient together with or without talking, *etc*. The behavioral observations were conducted in day shifts on weekdays by one of the authors who had done similar observations before [26].

Two sets of behavioral observations were conducted along a predefined route in each unit in a repeated loop. In one set, the locations and the numbers of participants of all the interactions were recorded on a floor plan as the author walked along the predefined route (**Figure 5**). In the other set, the lengths and

locations of interactions were recorded along the predefined route (**Figure 6**). As the length of an interaction was being recorded from its start to end all the other interactions that might have occurred in the unit were overlooked. Once the length of an interaction was recorded, the author would then focus her attention to the next interaction that might have just started along her route. The author would continue recording the lengths of interactions one after another until she reached the end of her predefined path.

At the end of a five-day data collection phase, the locations of 2233 interactions, and the location and length of another 339 interactions were recorded. The location of each interaction was assigned to a line in the axial map or to a cell in the visibility graph analysis as shown in **Figures 7 & 8**. When located on more than one line or cell, an interaction was assigned to the line/cell with the highest values for the measures of physical and visual accessibilities. The relationships between the frequency of interaction, the mean length of interaction, and the amount of interaction time at different locations and the physical and visual accessibilities of these locations in the two ICUs were investigated using correlational and regression analyses.

Findings and discussion

Hypothesis 1: *Overall, open-plan ICUs will be more physically and visually accessible than racetrack ICUs*.

Partially supporting the hypothesis, when compared with the racetrack ICU the open-plan ICU is visually more accessible at the cell and subsystem levels as measured using visual connectivity and integration-R3, but is visually less accessible at the system level as measured using visual integration-Rn (**Table 2**). Also partially supporting the hypothesis, when compared with the racetrack ICU the open-plan ICU is physically more accessible at the line level as measured using axial connectivity, but is physically less accessible at the subsystem and global levels as measured using axial integration-R3 and -Rn. (**Table 2**).

In general, these findings indicate that the open-plan ICU is physically and visually more accessible at the line/cell and subsystem levels, and the racetrack ICU is physically and visually more accessible at the system level. They can be explained by the fact that the open-plan ICU lacks permanent privacy barriers around patient rooms enhancing physical and visual accessibilities at the line/cell and subsystem levels. In contrast, the racetrack ICU includes permanent barriers around patient rooms reducing physical and visual accessibilities at the line/cell and subsystem levels.

However, patient rooms or spaces are only a part of the whole ICU environment. ICUs generally require many support and service spaces including nurse stations, supplies and equipment rooms, nutrition rooms, soil rooms, staff lounge, and family amenities. The layout of these support and service spaces often affects the overall physical and visual accessibilities of ICUs. This may then help explain why, according to this study, the open-plan ICU is physically and visually less accessible than the racetrack ICU at the system level.

Hypothesis 2: *The primary workspaces of clinicians in open-plan ICUs will be physically and visually more accessible than those in racetrack ICUs*.

Supporting the hypothesis, when compared with those in the racetrack ICU the primary workspaces of clinicians in the open-plan ICU are visually more accessible at the cell, subsystem and system levels as measured using visual connectivity, integration-R3 and integration-Rn. Partially supporting the hypothesis, when compared with those in the racetrack ICU the primary workspaces of clinicians in the open-plan ICU are physically more accessible at the line and subsystem levels as measured using axial connectivity and integration-R3, but they are physically less accessible at the system level as measured using axial integration-Rn (**Table 3**).

As per our previous findings on Hypothesis 1, since the open-plan ICU is physically and visually more accessible than the racetrack ICU at the line/cell and subsystem levels, it makes sense that clinicians'

primary workspaces are also physically and visually more accessible at the line/cell and subsystem levels in the open-plan ICU than in the racetrack ICU. Interesting, however, is the fact that the primary workspaces of clinicians in the open-plan ICU are visually more accessible than those in the racetrack ICU at the system level when the open-plan ICU as a whole is not visually more accessible than the racetrack ICU (refer to **Table 2**). Concerning this, it should be noted that the ease of patient monitoring and care is only one of many other factors dictating the locations of clinicians' workspaces in ICUs. These factors may include organizational culture, clinical models, technology integration, and space availability. It is possible that the primary workspaces of clinicians are visually more accessible in the open-plan ICU than in the racetrack ICU at the system level because of these factors.

Hypothesis 3: *Most clinicians will know their peers in the unit, but physical and visual accessibilities of ICU clinicians' primary workspace will affect how many will they know their peers.*

Our findings show that a majority of ICU clinicians know all their peers in both ICUs (**Table 4**). Our findings also show that ICU clinicians who know all their peers in the unit are located in physically and visually more accessible workspaces at the line/cell, subsystem, and system levels than those who do not know all their peers in the unit (**Table 4**). Additionally, our findings show that ICU clinicians who know all their peers in the open-plan ICU are located in physically and visually more accessible workspaces at the line/cell, subsystem, and system levels than those who know all their peers in the racetrack ICU (**Table 4**).

Our findings are important, because acquaintance is necessary to know each other at work. Such acquaintance may develop if clinicians work closely in teams or if they are located close to each other. Since teamwork is frequent in ICUs and since ICUs are relatively small workplaces, it makes sense that most ICU clinicians know all their peers in the unit. It also makes sense that ICU clinicians who know all their peers in the unit are located in spaces with more physical and visual accessibilities because these

spaces give more opportunities to develop acquaintances. Conversely, ICU clinicians who do not know all their peers in the unit are located in spaces with less physical and visual accessibilities because these spaces give fewer opportunities to develop acquaintances. According to our findings, the open-plan ICU may provide more opportunities for developing acquaintances than the racetrack unit.

Hypothesis 4: *Physical and visual accessibilities of ICU clinicians' primary workspaces will affect how well they know where others are located in the unit.*

Our findings indicate that individuals' awareness of where others are located in the unit is better in the open-plan ICU than in the racetrack ICU. When asked "if you know the locations of other clinicians working on the unit," 67.6% of the survey participants in the open-plan ICU as opposed to 25.5% in the racetrack ICU agreed (**Table 5**). Our findings also indicate that the number of clinicians who know the locations of others is fewer than the number of clinicians who do not know the locations of others in the racetrack ICU. In contrast, the number of clinicians who know the locations of others ICU is higher than the number of clinicians who do not know the locations of others in the open-plan ICU (**Table 5**).

Our findings can be explained by the fact that better physical and visual accessibilities are required to know others' locations in the unit. Since the open-plan ICU provides better physical and visual accessibilities than the racetrack ICU, as we have found before, it makes sense that the number of clinicians who know the locations of their peers is higher in the open-plan ICU than in the racetrack ICU. It should, however, be noted that the locations of clinicians and their work assignments constantly change in ICUs. In the racetrack ICU where physical and visual accessibilities are poor and one can see only a few, we may assume that only clinicians with managerial responsibilities (e.g., nurse managers, charge nurses, *etc.)* would know where everyone is located in the unit. We may also assume that these clinicians with managerial responsibilities would have more private, hence less physically and visually accessible

spaces in the ICU. This may help explain why fewer clinicians know the locations of others in the racetrack ICU; and why they are located in physically and visually less accessible spaces (**Table 5**).

In contrast, in the open-plan ICU where physical and visual accessibilities are better and one can see many, many clinicians including those with managerial responsibilities know where everyone is located in the unit. As a result, as indicated by our findings, the primary workspaces of these clinicians are not physically and visually more accessible, because they include clinicians with managerial responsibilities. In contrast, as indicated by our findings, clinicians who do not know the locations of others in the open-plan ICU are likely to be those with no or less managerial responsibilities; hence, they are located in less private spaces with more physical and visual accessibilities (**Table 5**).

Hypothesis 5: *Physical and visual accessibilities of ICU clinicians' primary workspaces will affect their perception of how well a unit supports interaction and communication*.

When asked "if interaction and communication are better when peers are located close within sight," 93.9% of the survey participants in the 32-bed open unit and 84.8% of the participant in the 28-bed racetrack unit agreed (**Table 6**).Given the presumed importance of physical and visual accessibilities in ICUs, the finding is not surprising. It emphasizes the fact that the importance of better physical and visual accessibilities in ICUs has not diminished due to changes in critical care technology, practice and culture; and still today ICU clinicians consider better physical and visual accessibilities as important for interaction and communication in both open-plan and racetrack ICUs.

According to our findings, the associations between physical and visual accessibilities and their importance for interaction and communication, however, are different in the two ICUs. In the racetrack ICU with less physical and visual accessibilities, more clinicians' workstations are located at physically and visually less accessible spaces (**Table 6**) experiencing less interaction and communication. As a

result, when clinicians in the race-track ICU agree that it is necessary for peers to be located close within sight for better interaction and communication they do so because they feel the need for it.

In contrast, in the open-plan ICU with better physical and visual accessibilities, more clinicians' are located at physically and visually more accessible spaces (**Table 6**) experiencing more interaction and communication. Therefore, when they agree that it is necessary for peers to be located close within sight for better interaction and communication they do so because they experience the benefit of having peers close within sight.

Hypothesis 6: *Physical and visual accessibilities of ICU clinicians' primary workspaces will affect their perception of how well a unit supports teamwork and collaboration.*

85.3% of the survey participants in the open-plan unit as opposed to 44.4% in the racetrack unit agreed that their units provide opportunities for teamwork and collaboration (**Table 7**). Given our earlier finding that the racetrack ICU has less physical and visual accessibilities than the open-plan ICU, it makes sense that clinicians who agree that their unit provides better opportunities for teamwork and collaboration are fewer in the racetrack ICU and more in an open-plan ICU than those who do not agree (**Table 7**).

In racetrack units where physical and visual accessibilities are poor, fewer clinicians are located at physically and visually less accessible spaces with more opportunities for teamwork and collaboration. Therefore, fewer clinicians agree that racetrack units provide better opportunities for teamwork and collaboration (**Table 7**). In contrast, in open-plan units where physical and visual accessibilities are better, more clinicians' are located at physically and visually more accessible spaces with more opportunities for teamwork and collaboration. Therefore, more clinicians agree that open-plan units provide better opportunities for teamwork and collaboration (**Table 7**).

Hypothesis 7: *Physical and visual accessibilities of ICU will affect the frequency and length of interactions in ICUs.*

In correlational analyses, various measures of physical and visual accessibilities show significant associations with interaction frequency for the ICUs, taken together and separately. These associations, however, are particularly strong for the open-plan ICU (**Table 8**). Various measures of physical and visual accessibilities also show significantly strong associations with the mean length of interactions and the total amount of interaction time for the open-plan ICU. In contrast, these measures do not show any associations with the mean length of interactions and the total amount of interaction time for the racetrack ICU (**Table 8**).

These findings of the correlational analyses give us some preliminary explanations for why a majority of ICU clinicians in the open-plan ICU agree that this layout provides better opportunities for interaction and communication and for teamwork and collaboration. According to these findings, better physical and visual accessibilities encourage more frequent and longer interactions in the open-plan ICU. These, in turn, positively affect ICU clinicians' perception of opportunities for interaction and communication and for teamwork and collaboration.

In order to find out if the variations in the frequency of interactions, the mean length of interactions and the total amount of interactions observed at different locations within the two units, together and separately, could be explained by the measures of visual and physical accessibilities, regression models were used. In these models, the measures of visual accessibilities followed by the measures of physical accessibilities were entered as the predictor variables with the number of interactions, the total amount of interaction time or the mean interaction time observed at different locations as the dependent variable (**Tables 9 & 10**).

With both the ICUs considered in the regression models, adjusted R-squared, which adjusts the statistic based on the number of predictor variables in the model, shows that 25% of the variations in the number

of interactions is explained by the three measures of visual accessibilities at a significance level of .00. After the measures of physical accessibilities are entered in the equation, however, the amount of variations explained drops to 23%, but the model remains significant (**Table 9**). These findings indicate that physical accessibilities may be less important than visual accessibilities in explaining the variation in the number of interactions observed in various locations in these units. It should however be noted here that, according to our regression models, visual and physical accessibilities do not explain the variations in the total amount of interaction time or the mean interaction time observed at different locations of these units(**Table 9**).

With each unit considered separately in the regression models, adjusted R-squared shows that 23% and 34% of the variations in the number of interactions are explained by the three measures of visual accessibilities in the racetrack and open-plan ICUs, respectively, at a significance level of .00. After the measures of physical accessibilities are entered in the models, however, the amount of variations explained increases from 23% to 25% for the racetrack ICU, but drops from 34% to 29% for the open-plan ICU with the models showing significance (Sig. = .00 and .01) (**Table 10**). These findings indicate, again, that physical accessibilities may be less important than visual accessibilities in explaining the variations in the number of interactions observed in various locations in these units.

With each unit considered separately in the regression models, adjusted R-squared also shows that 21% and 23% of the variations in the total amount of interaction time are explained by the three measures of visual accessibilities in the racetrack and open-plan ICUs, respectively, with the models being somewhat significant (Sig. = .09 and .06). After the measures of physical accessibilities are entered in the models, however, the amount of variations explained drops from 21% to 14% and from 23% to 11% for the racetrack and open-plan ICU, respectively, with the models showing a lack of significance (Sig. = .26 and .28) (**Table 10**). These findings indicate, once again, that physical accessibilities may be less important than visual accessibilities in explaining the variations in the amount of interaction time at various locations in any one of these units

With each unit considered separately in the regression models, adjusted R-squared further shows that 28% and 23% of the variations in the mean length of interactions are explained by the three measures of visual accessibilities in the racetrack and open-plan ICUs, respectively, with the models being significant (Sig. = .05 and .06). After the measures of physical accessibilities are entered in the models, however, the amount of variations explained drops from 28% to 19% and from 23% to 11% for the racetrack and open-plan ICU, respectively, with the models showing a lack of significance (Sig. = .20 and .27) (**Table 10**). These findings indicate, for one more time, that physical accessibilities may be less important than visual accessibilities in explaining the variations in the length of interactions at various locations in any one of these units.

Summary and Conclusions

This study looked at various aspects of physical and visual accessibilities in an open-plan and a racetrack ICU. First, it compared physical and visual accessibilities in these ICUs using various objective measures derived based on the spatial analysis techniques of Space Syntax. Following this, the study compared the two ICUs based on clinicians' perception of the need for physical and visual accessibilities in relation to how well they know their peers in the unit, how well they know where others are located in the unit, opportunities for interaction and communication, and opportunities for teamwork and collaboration. Finally, the study compared the effects of physical and visual accessibilities on the number of interaction, the total amount of interaction time and the mean length of interactions at different locations in these ICUs.

According to the findings of the study, physical and visual accessibilities are different in the two ICUs, with the open-plan ICU showing better physical and visual accessibilities at the cell/line and subsystem levels. As a result, as the study shows, clinicians' primary workplaces are also physically and visually more accessible in the open-plan ICU than in the racetrack ICU. The study also shows that ICU clinicians

who know their peers and where their peers are located in the units occupy physically and visually more accessible workplaces, because these spaces give more opportunities to develop acquaintances. Additionally, the study shows that clinicians' perception of interaction and communication and of teamwork and collaboration in ICUs are affected by the physical and visual accessibilities of their primary workspaces. Furthermore, according to the findings of the study, physical and visual accessibilities show significant positive associations with interaction frequency, with the open-plan unit showing stronger associations. Moreover, according to the findings of the study, physical accessibilities may be less important than visual accessibilities for explaining the variations in the number of interaction, the mean length of interaction and the amount of interaction time at various locations in any one of the two units.

The findings of the study, however, must be considered in light of the limitations of this study. Even though the two ICUs included in this study serve adult patients, use similar communication and collaboration technology, and are located next to each other on the same floor of a university teaching hospital, this study did not take into account the severity of patients in these units at the time of study. It is possible that interactions in these units were affected by this. In our defense, it should be noted that in this study we were not interested in the differences of interaction frequency and length in these units. Our interest was mostly focused on the relationships between various measures of physical and visual accessibilities, and interaction frequency and length. Such relationships are not likely to be dependent on patient severity within a unit.

Despite its limitations, the findings of the study raise an interesting dilemma concerning how best to design ICUs. In an ICU, private rooms are needed for improved privacy, infection control, and quality of care. In contrast, easy physical and visual accessibilities are needed in ICUs for increased safety through direct monitoring, more interactions, and improved satisfaction. A good ICU design must find a balance between privacy, and easy physical and visual accessibilities. The fact that most award-winning best-practice ICUs in the US are designed as race-track units may indicate that as the ICU design community

we might have already chosen privacy over easy physical and visual accessibilities, a choice that we may want to question in light of our findings reported here.

Nevertheless, it would be odd to think that anyone involved in designing ICUs deliberately undermines the importance of physical and visual accessibilities in ICUs when they choose a racetrack over an open-plan for an ICU. As it is for any other designed environments, people designing ICUs make choices within a set of given constraints. These choices are often shaped by the larger discourse on how we define what is important as much as they are shaped by the immediate needs of clients and users. In today's hyper-sensitive and hyper-connected world, securing individual privacy has become extremely important. As members of the ICU design community, we may not be immune against this social demand for increased individual privacy. We must therefore ask, "To what extent are we being influenced by the larger social climate as we emphasize privacy over physical and visual accessibilities in ICUs?" We must also ask, "How much of our need for privacy is a result of our technological capacity?"

In an age of tremendous technological growth, it is common to find arguments indicating that we have the necessary technological abilities to solve any issues of physical and visual accessibilities arising from private rooms in ICUs. Numerous monitoring devices, alarm systems, and big data analytics to support clinical decision-making – all can be used as examples here. There is no doubt that most of these technological devices could potentially help save lives while ensuring privacy and reducing the need for easy physical and visual accessibilities. Contrasting this, as our dependence on technology increases the distance between the patient and the caregiver also increases, making it difficult to develop a relationship based on empathy.

Yet, we must continue to use technology to save lives in ICUs. The reasons are quite simple. Humans are extremely complex biological systems with physical, psychological, cognitive and many other limitations. Due to their inherent limitations, humans are prone to make mistakes. In ICUs, the costs of these mistakes are high. In an attempt to reduce these mistakes and their associated costs, we have become increasingly

more dependent on technology and less dependent on our human abilities in taking good care of patients. In an age when our optimism with technology is high, we often forget our deep evolutionary relationships with and dependence on the physical environments around us defined, to a great extent, by physical and visual accessibilities. Why should we not then take advantage of physical and visual accessibilities in ICUs? According to our study, when we design a racetrack ICU with private patient rooms only, we may fail to exploit physical and visual accessibilities to enhance environmental awareness, interaction, communication, teamwork and collaboration. As result, we reduce many opportunities that could also help improve critical care in ICUs.

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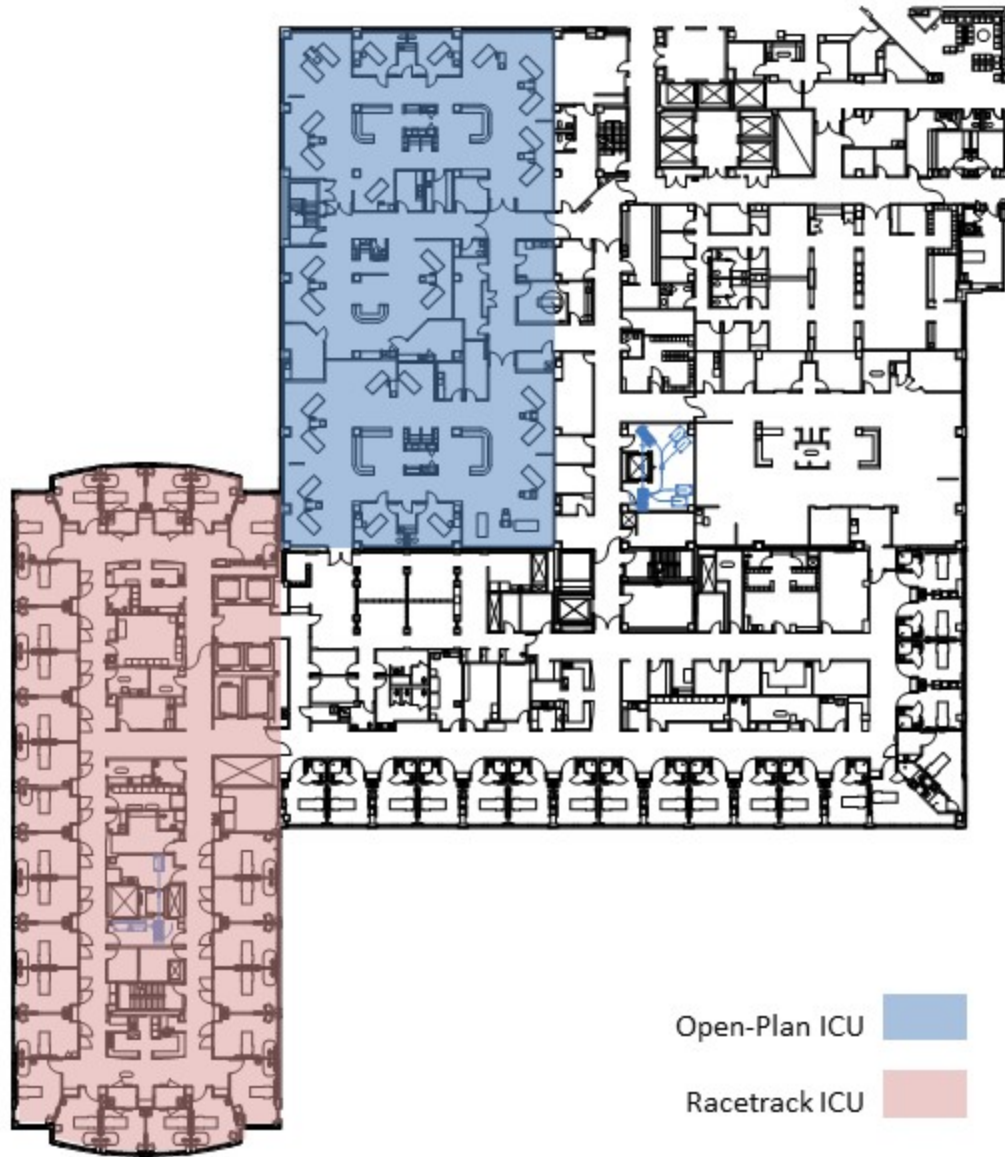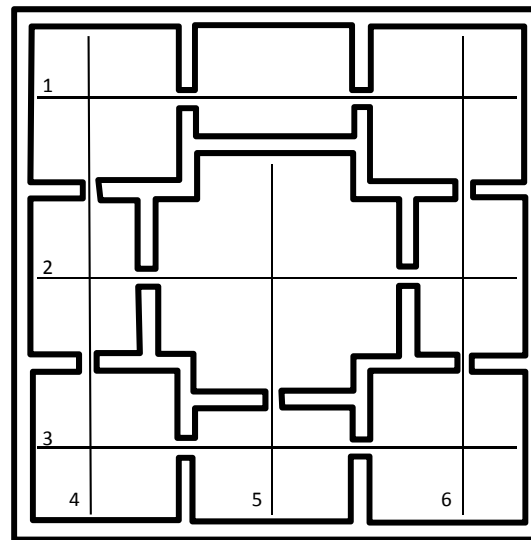
Figure 1. A plan of the open-plan and racetrack ICUs.
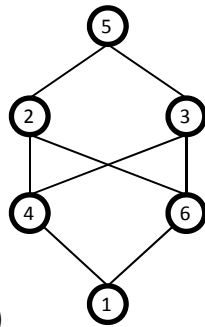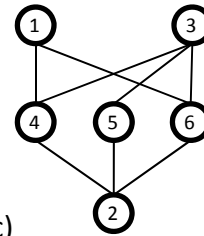
Figure 2. The basic concept of the axial map analysis: (a) A floor plan and its axial map. (b) The justified graph of axial line-1 shows that in order to get to all other axial lines from this line at least three steps are needed. (c) The justified graph of axial line-2 shows that in order to get to all other axial lines from this line only two steps are needed.
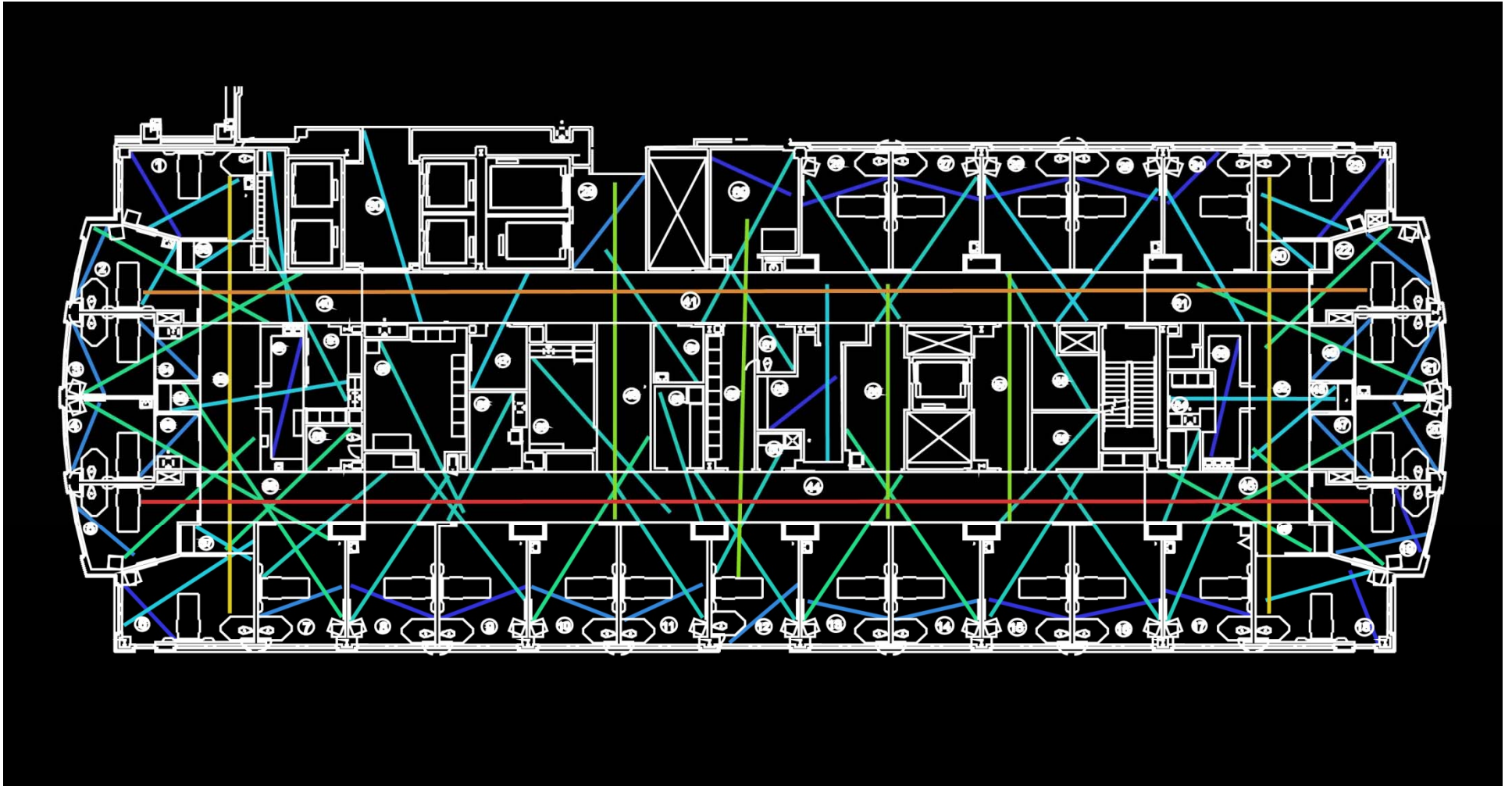
Figure 3. The axial map of the racetrack ICU colored using integration-Rn.
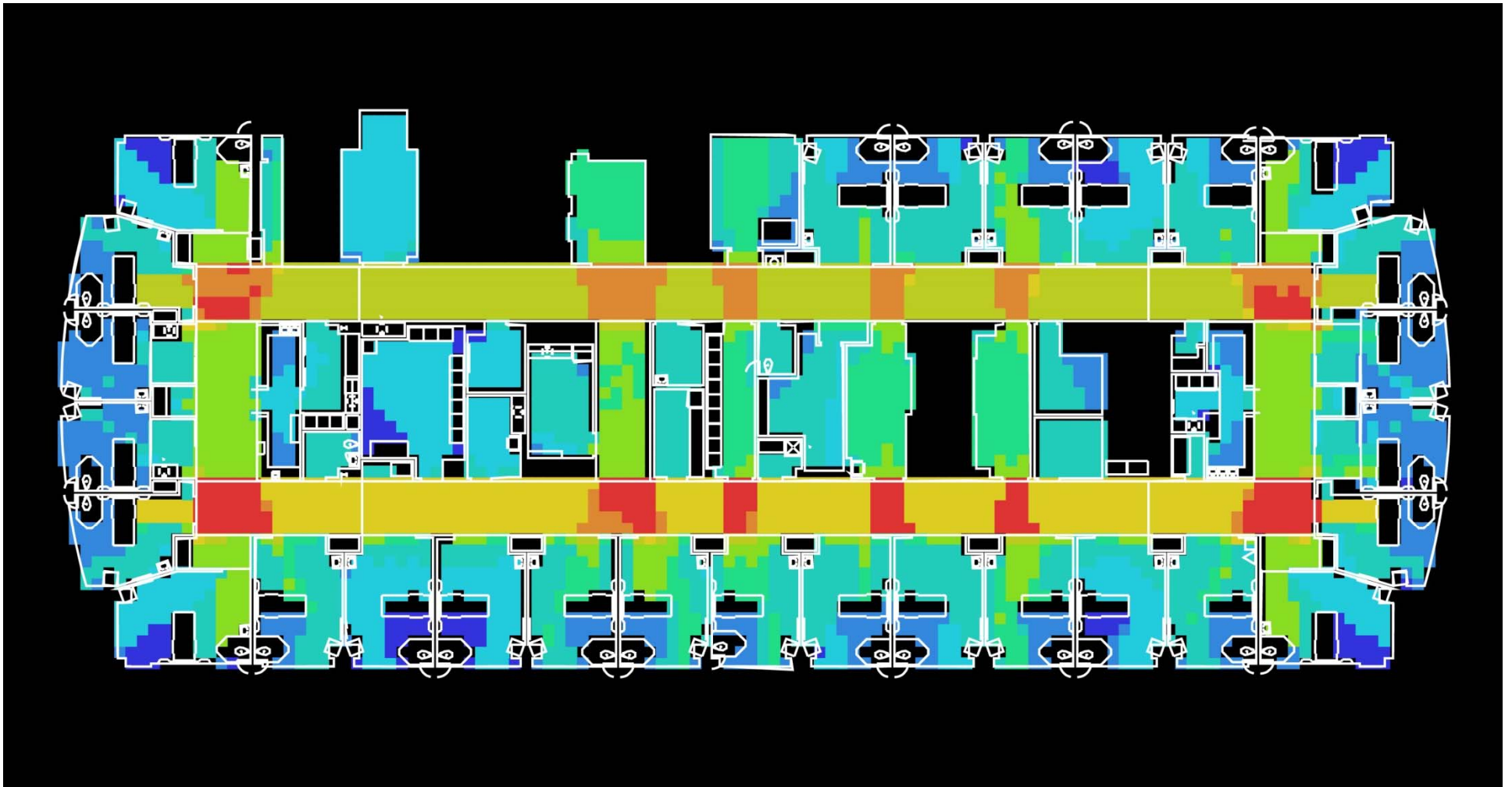
Figure 4. The visibility graph of the racetrack ICU colored using integration-Rn.
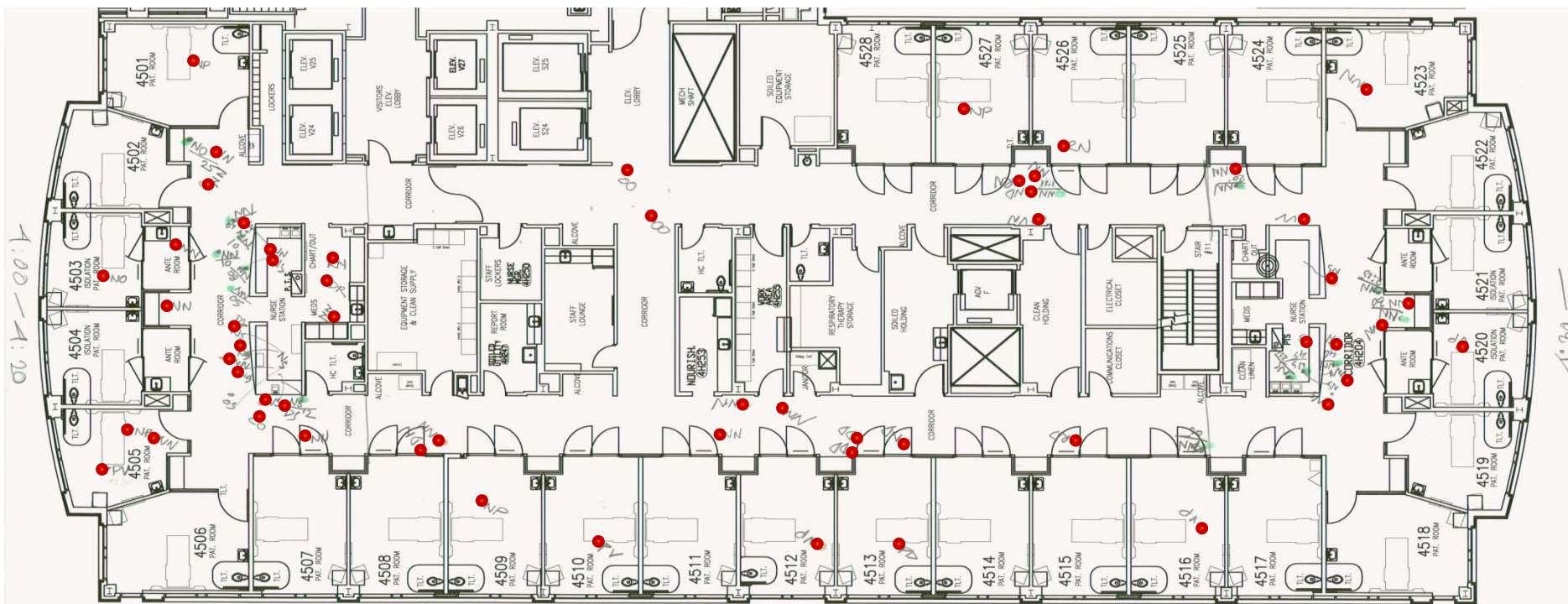
Figure 5. Locations of interactions observed during an observation round.
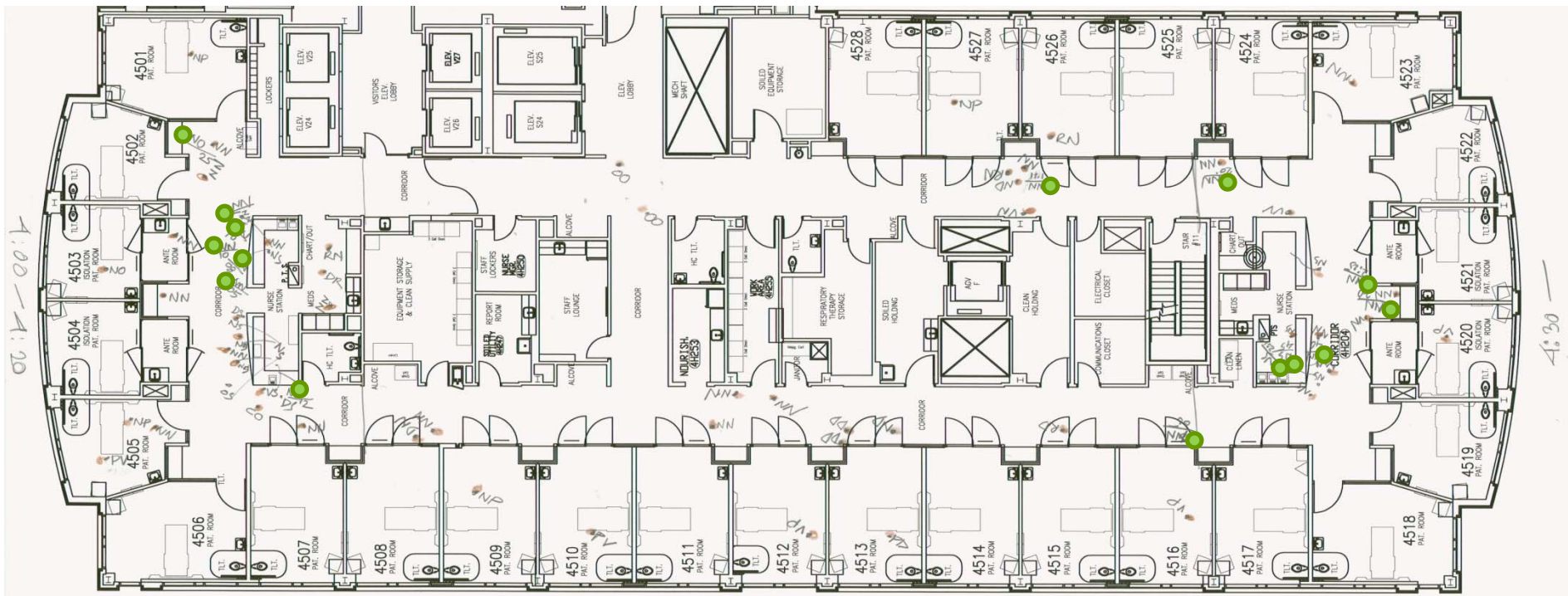
Figure 6. Locations of interactions observed with time during an observation round.
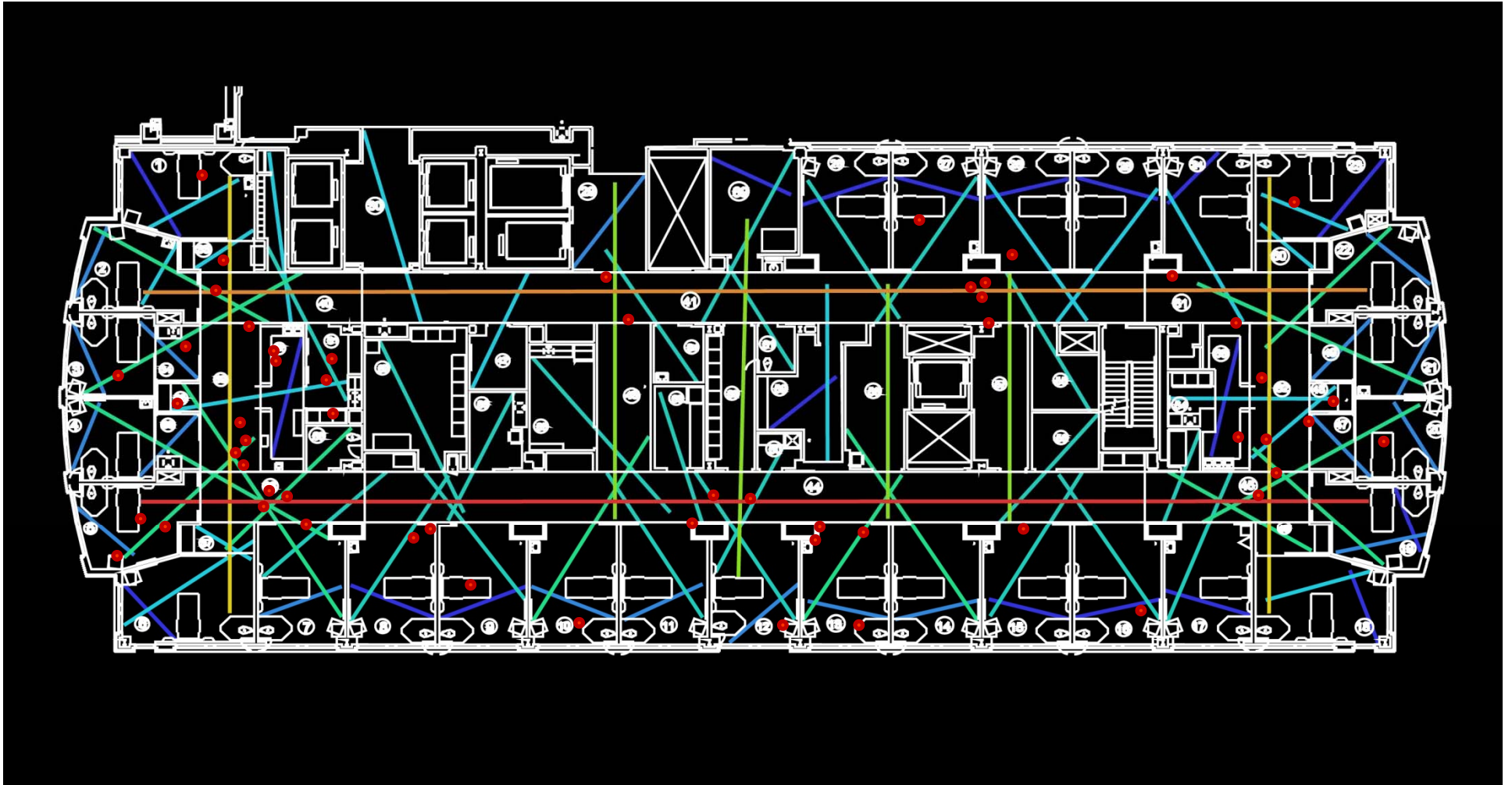
Figure 7. The locations of interactions relative to the axial map.
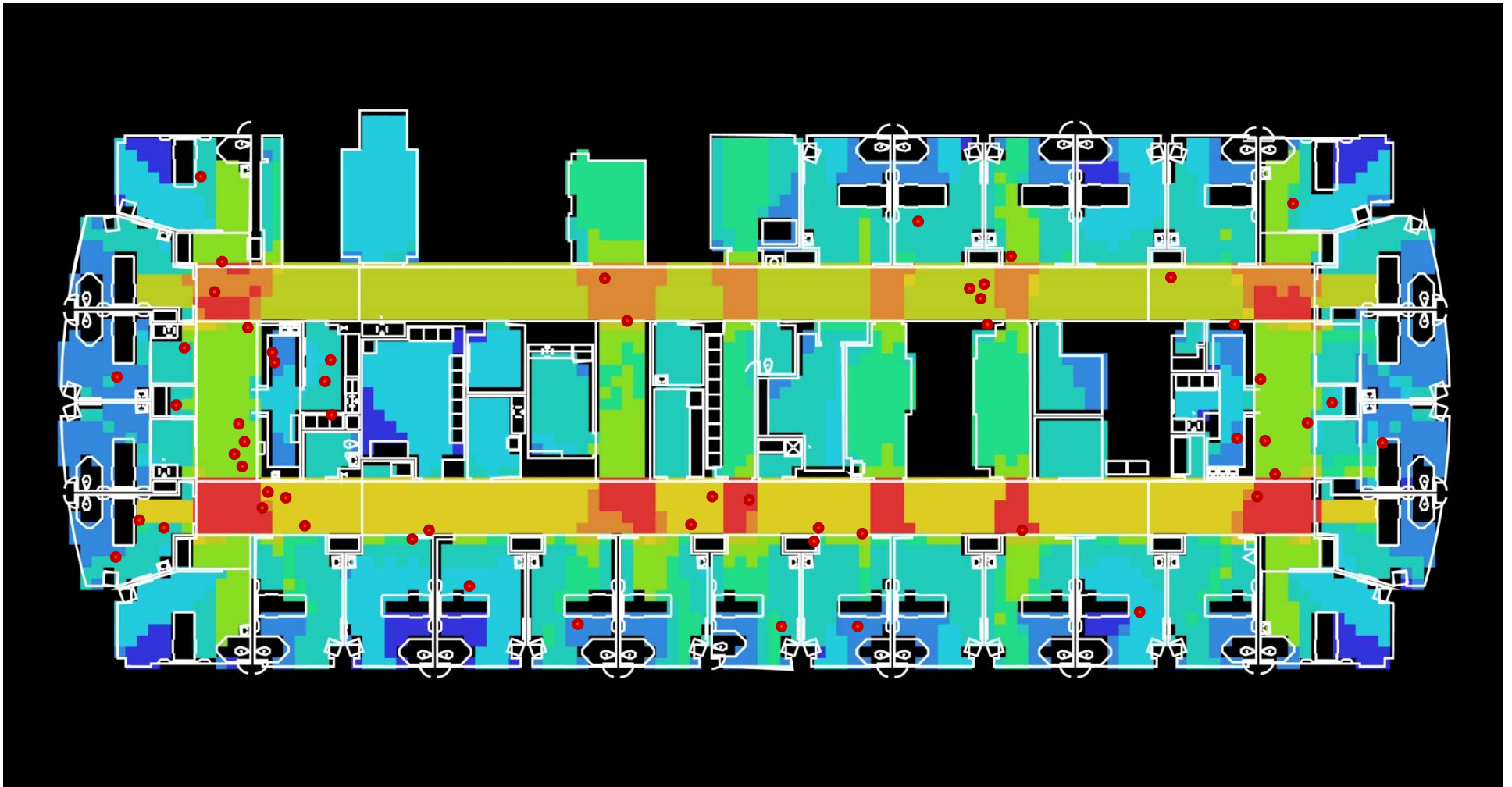
Figure 8. Locations of interactions relative to the visibility graph analysis.

Job Type	Both Units	28-Bed Racetrack Unit	32-Bed Open-Plan Unit
Registered Nurse	75.3	76.6	73.5
Charge Nurse	11.1	8.5	14.7
Other Nurse	11.1	12.8	8.8
Physician	2.5	2.1	2.9
Total	100.0	100.0	100.0

Table 1. Distribution of survey participants by job type.

Measures of Physical and visual accessibility						
Unit type	Visual connectivity	Visual integration (R3)	Visual integration (Rn)	Axial connectivity	Axial integration (R3)	Axial integration (Rn)
28-Bed Racetrack Unit	236.28	5.90	**5.00**	3.32	**2.11**	**1.96**
32-Bed Open-Plan Unit	**240.81**	**6.00**	4.51	**4.58**	2.04	1.68

Table 2. Measures of Physical and visual accessibilities in units (bold showing larger values).

Measures of physical and visual accessibilities of primary workplaces of survey participants						
	Visual connectivity	Visual integration (R3)	Visual integration (Rn)	Axial connectivity	Axial integration (R3)	Axial integration (Rn)
28-Bed Racetrack Unit	220.00	5.72	4.84	11.69	2.98	**2.72**
32-Bed Open-Plan Unit	**343.11**	**6.56**	**5.06**	**16.64**	**3.21**	2.60

Table 3. Measures of physical and visual accessibilities of primary workplaces of survey participants (bold showing larger values).

				Know the names of other clinicians working on the unit				
Unit type		% of participants	Visual connectivity	Visual integration (R3)	Visual integration (Rn)	Axial connectivity	Axial integration (R3)	Axial integration (Rn)
28-Bed Racetrack Unit	yes	**73.9**	**243.68**	**5.81**	**4.94**	**12.96**	**3.07**	**2.81**
	no	26.1	156.07	5.43	4.54	7.88	2.69	2.45
32-Bed Open-Plan Unit	yes	**73.5**	**359.68**	**6.63**	**5.18**	**17.81**	**3.28**	**2.71**
	no	26.5	293.38	6.33	4.72	13.14	2.99	2.27

Table 4. Distribution of responses for "know the names of other clinicians working on the unit" and measures of physical and visual accessibilities of primary workplaces of respondents (bold showing larger values).

		Know the locations of other clinicians working on the unit						
Unit type		% of participants	Visual connectivity	Visual integration (R3)	Visual integration (Rn)	Axial connectivity	Axial integration (R3)	Axial integration (Rn)
28-Bed Racetrack Unit	yes	25.5	146.50	5.24	4.35	8.20	2.70	2.45
	no	**74.5**	**248.27**	**5.90**	**5.03**	**13.04**	**3.09**	**2.83**
32-Bed Open-Plan Unit	yes	**67.6**	309.18	6.42	4.79	15.00	3.04	2.43
	no	32.4	**427.94**	**6.91**	**5.74**	**20.75**	**3.63**	**3.01**

Table 5. Distribution of responses for "know the locations of other clinicians working on the unit" and measures of physical and visual accessibilities of primary workplaces of respondents (bold showing larger values).

Better interaction and communication when peers located close within sight								
Unit type		% of participants	Visual connectivity	Visual integration (R3)	Visual integration (Rn)	Axial connectivity	Axial integration (R3)	Axial integration (Rn)
28-Bed Racetrack Unit	yes	84.5	215.39	5.68	4.81	11.66	2.98	2.73
	no	15.2	**271.04**	**6.08**	**5.18**	**13.17**	**3.13**	**2.85**
32-Bed Open-Plan Unit	yes	93.9	**357.89**	**6.62**	**5.17**	**17.38**	**3.26**	**2.67**
	no	6.1	150.99	5.77	3.68	7.00	2.49	1.70

Table 6. Distribution of responses for "better interaction and communication when peers located close within sight" and measures of physical and visual accessibilities of primary workplaces of respondents (bold showing larger values).

Unit provides opportunities for teamwork and collaboration								
Unit type		% of participants	Visual connectivity	Visual integration (R3)	Visual integration (Rn)	Axial connectivity	Axial integration (R3)	Axial integration (Rn)
28-Bed Racetrack Unit	yes	44.4	227.42	**5.80**	4.89	11.73	**3.05**	**2.78**
	no	55.6	**232.31**	5.78	**4.93**	**12.47**	3.01	2.76
32-Bed Open-Plan Unit	yes	85.3	**357.02**	**6.62**	**5.12**	**17.31**	**3.25**	**2.64**
	no	14.7	162.20	5.73	4.27	8.00	2.67	2.01

Table 7. Distribution of responses for "unit provides opportunities for teamwork and collaboration" and measures of physical and visual accessibilities of primary workplaces of respondents (bold showing larger values).

	Total number of interactions observed at a location			Total amount of interaction time at a location (seconds)			Mean interaction time at a location (seconds)		
	Both Units	28-Bed Racetrack Unit	32-Bed Open-Plan Unit	Both Units	28-Bed Racetrack Unit	32-Bed Open-Plan Unit	Both Units	28-Bed Racetrack Unit	32-Bed Open-Plan Unit
Visual connectivity	.512[**]	.477[**]	.601[**]	.276	.052	.526[*]	.291	.119	.526[*]
Visual integration (R3)	.458[**]	.417[**]	.611[**]	.263	.088	.553[**]	.280	.165	.552[**]
Visual integration (Rn)	.418[**]	.430[**]	.434[**]	.333[*]	.151	.550[**]	.345[*]	.231	.551[**]
Axial connectivity	.414[**]	.386[**]	.491[**]	.278	.099	.450[*]	.291	.158	.451[*]
Axial integration (R3)	.347[**]	.339[*]	.402[*]	.301	.209	.460[*]	.312	.277	.461[*]
Axial integration (Rn)	.317[**]	.350[*]	.418[**]	.297	.252	.491[*]	.303	.323	.491[*]

Pearson Correlation

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 8. Correlations between measures of physical and visual accessibilities and the frequency of interaction, the amount of interactions, and the mean length of interaction.

Dependent Variable: Number of Interactions Observed						
Unit ID		R	R Square	Adjusted R Square	F	Sig.
Both Units	1	.52[a]	0.28	0.25	11.17	0.00
	2	.53[b]	0.28	0.23	5.59	0.00
Dependent Variable: Total amount of Interaction Time						
Both Units	1	.34[a]	0.12	0.04	1.60	0.20
	2	.37[b]	0.14	-0.02	0.90	0.51
Dependent Variable: Mean Interaction Time						
Both Units	1	0.35[a]	0.12	0.05	1.69	0.19
	2	0.39[b]	0.15	0.00	0.97	0.46

a. Predictors: (Constant), Visual connectivity, Visual integration (R3), Visual integration (Rn)

b. Predictors: (Constant), Visual connectivity, Visual integration (R3), Visual integration (Rn), Axial connectivity, Axial integration (R3), Axial integration (Rn)

Table 9. Results of the regression analyses for both the ICUs.

Dependent Variable: Number of Interactions Observed						
Unit ID		R	R Square	Adjusted R Square	F	Sig.
28-Bed Racetrack Unit	1	.52[a]	.27	.23	6.02	.00
	2	.58[b]	.34	.25	3.81	.00
32-Bed Open-Plan Unit	1	.63[a]	.39	.34	7.76	.00
	2	.63[b]	.40	.29	3.70	.01
Dependent Variable: Total amount of Interaction Time						
28-Bed Racetrack Unit	1	.59[a]	.35	.21	2.64	.09
	2	.65[b]	.43	.14	1.49	.26
32-Bed Open-Plan Unit	1	.59[a]	.35	.23	3.04	.06
	2	.61[b]	.38	.11	1.42	.28
Dependent Variable: Mean Interaction Time						
28-Bed Racetrack Unit	1	.63[a]	.40	.28	3.30	.05
	2	.68[b]	.46	.19	1.71	.20
32-Bed Open-Plan Unit	1	.59[a]	.35	.23	3.03	.06
	2	.62[b]	.38	.11	1.43	.27

a. Predictors: (Constant), Visual connectivity, Visual integration (R3), Visual integration (Rn)

b. Predictors: (Constant), Visual connectivity, Visual integration (R3), Visual integration (Rn), Axial connectivity, Axial integration (R3), Axial integration (Rn)

Table 10. Results of the regression analyses for each of the ICUs.