

Inpatient unit visibility, space use, and social networks of communication

Research Article

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Abstract: Care team communication is fundamental to most healthcare environments, but the dynamic ways that care team workers use space complicate knowing how to best design for communication in hospital spaces. This comparative case study of two inpatient units used floorplan-based measures of visibility, behavior mapping, and social network analysis to gain insight into the relationship of floorplan layout to care team social networks of communication. Greater unit visibility appears to create conditions for copresence that enhance care team communication.

Keywords: Nurse communication • Social network analysis • Floorplan layout • Hospital • Space syntax

1. Introduction

1.1 Inpatient unit visibility, space use, and social networks of communication

This article originates from a practical request from several members of the care team at a community hospital in the midwestern United States. Before designing a new inpatient unit in a vertical tower expansion, care team workers expressed that they felt isolated at work and that the care team should be more connected in the new design. Their concerns reflect a fundamental dilemma of nurse work; the nurse is pulled toward both the patient's bedside to provide care and away from the patient to work with the other members of the care team (Ossmann, 2022), often at a team nurse station. This exploratory case study follows from the hospital organization and the design team taking these care workers at their word, aiming to design for greater connection, and now conducting analyses to probe whether the design strategies used had their intended effect.

The purpose of this article is to compare these two hospital inpatient units – an older medical-surgical unit (MSU) and a newer acuity adaptable unit (AAU) – to gain insight into how care team communication networks may be shaped by design, especially the kinds of visibility conditions that arise from floorplan layout. Our theoretical orientation draws on concepts from ecological psychology that recognize the pervasive impact of context-as-perceived on action (Barker, 1968; Clark & Chalmers, 1998; Gibson, 1979). Our research approach accordingly focuses on the physical and social contexts of care team communication. Understanding various contexts of social networks is an emerging research field with growing popularity in the domain of social network analysis (SNA), as evidenced by a series of special issues in relevant journals (Adams et al., 2012; De Benedictis et al., 2015; Doehne et al., 2024). Our approach here contributes to this discourse.

1.2 The importance of care team communication

Care team communication is fundamental to healthcare provision and is a prime determinant of the quality and

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safety of patient care. Previous studies have recognized that teamwork between members of the care team is important for improving care quality and moderating safety lapses (Havyer et al., 2014; Joint Commission, 2023; Kalisch et al., 2013; Weller et al., 2014). In addition, interprofessional collaboration has been demonstrated to improve a range of patient outcomes, including patient survival, functioning, and readmissions (Martin et al., 2010). In healthcare environments, face-to-face communication may be especially relevant. For example, González-Martínez et al. (2016) found that corridor conversations provided opportunities for rapid, unplanned exchanges of information on patient status.

In hospital units, the physical environment has been identified as a factor influencing communication and team-based care (Kalisch et al., 2013). Previous studies have indicated that aspects of the designed environment that promote teamwork include proximity and intervisibility between members of the care team (Doede et al., 2018; Gharaveis et al., 2018; Gunn et al., 2015; Kalisch et al., 2013; Pachilova & Sailer, 2022). Previous studies additionally converge on the spatial centrality of key functions as contributing to care team communication (Brewer et al., 2018; Copeland & Chambers, 2017; Hua et al., 2012; Stevens et al., 2012). When key programmatic elements are centralized, care team members are more likely to see or encounter their colleagues as they access those spaces; for example, one might see a nurse colleague as they go to and from the medication room.

These tendencies in the research findings imply a conceptual framework in which design impacts teamwork indirectly, through the ways that it shapes patterns of copresence. Copresence, for its part, is the foundational prerequisite for face-to-face communication. Put another way, the effects of spatial configuration are not only on individuals but also on collections of individuals and how they interrelate through space: that is “a pattern of space in a complex can affect the pattern of co-presence and co-awareness of collections of people who inhabit and visit that complex” (Hillier, 2007, p. 293). Such patterns of copresence can be relatively static (e.g., colleagues charting at adjacent decentralized nurse stations) or more fleeting (e.g., seeing a colleague pass down a run of corridor).

The method for this exploratory case study is built around describing hospital space and use associated with each part of the conceptual framework: design – particularly as related to visual connections, patterns of copresence, and care team communication networks.

2. Methodological background

2.1 Characterizing design: viewsheds and floorplan layout

A central challenge to studies on the effects of hospital design is the difficulty of finding valid and reliable measures for characterizing environments (Jimenez et al., 2019). For this study of inpatient unit design, we use measures of floorplan layout properties. Floorplan layouts shape patterns of visibility and contact, they convey sociologically relevant information, and they are stable compared with some elements of the built environment, like furniture and finishes (Bafna, 2003).

We analyze floorplans with respect to their viewshed properties using measures and techniques from space syntax. Space syntax is a family of theories and measures aimed at elucidating the social functions of building space by analyzing layouts (Hillier & Hanson, 1984; Zook & Sailer, 2021). Specifically, our measures rely on systematic evaluation of the 360°, two-dimensional viewshed. (Note: *Viewshed* is used here for simplicity; the concept was coined as the *isovist* by Tandy (1967) and developed and applied to architecture since Benedikt (1979).) The viewshed delineates what is visible from any given point on a plan, accounting for any walls, columns, and other occlusions.

We characterize hospital unit viewsheds by their size and the degree to which they integrate and reach into the rest of the floorplan layout. Size is simply conveyed by area. To assess how viewsheds relate to the rest of the plan, we draw on the concepts of integration and isovist connectivity as developed in space syntax. An illustration of viewsheds and isovist connectivity appears in Figure 1.

The space syntax measures are explained in detail in Section 3. Previous hospital studies have linked viewshed properties, as characterized by space syntax measures, to inpatient safety (Choi, 2011; Ossmann et al., 2019; Ossmann, 2022) and care team function (Cai & Zimring, 2012; Lu & Zimring, 2011; Pachilova & Sailer, 2019, 2022; Zook et al., 2024).

2.2 Characterizing patterns of copresence: behavior mapping

As per our conceptual model, floorplan layout properties give rise to patterns of copresence, and copresence is a prerequisite for in-person communication. We used beha-

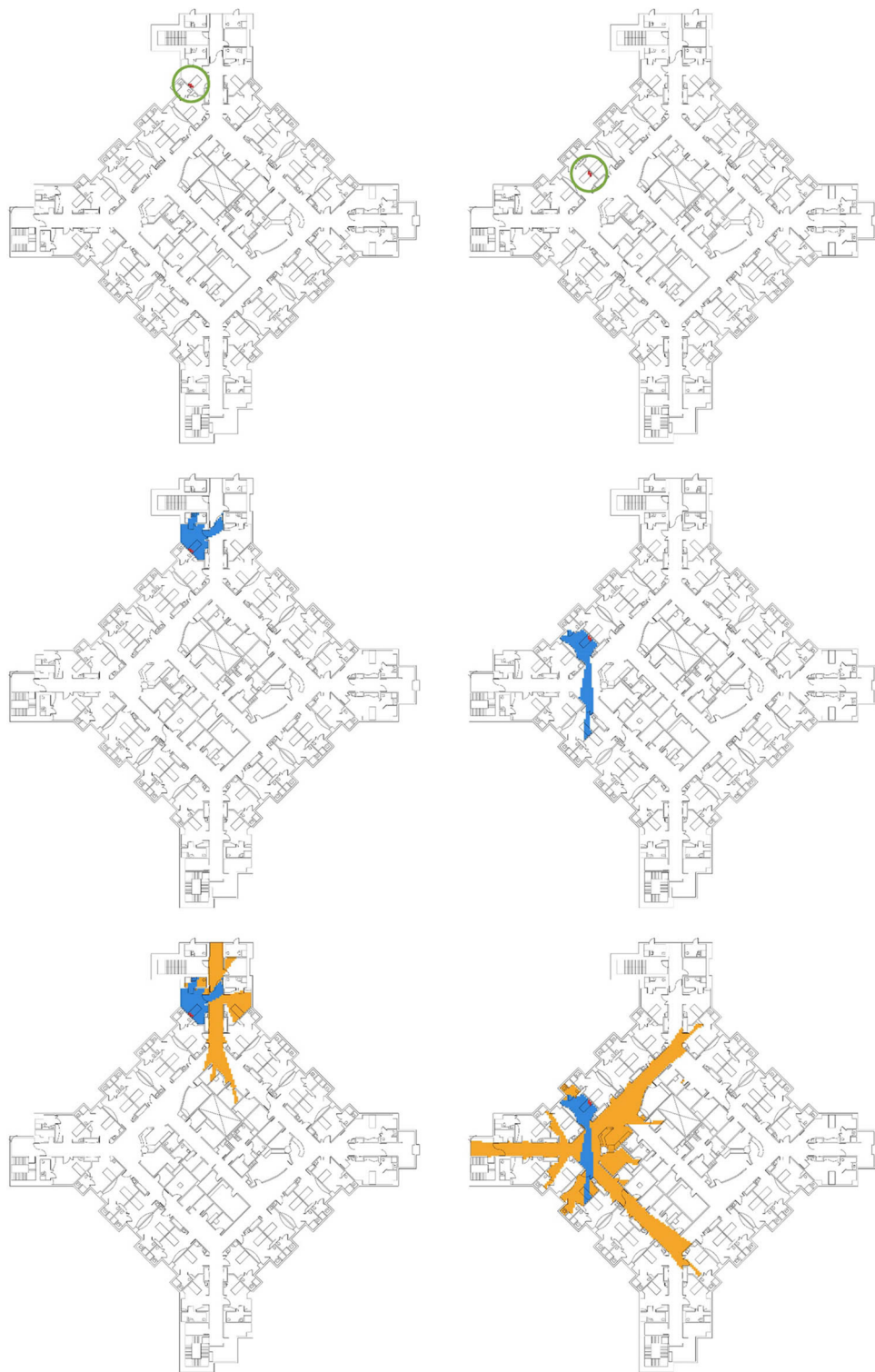


Figure 1. View origins, viewsheds, and isovist connectivity diagrams for two patient heads-of-bed. Note: The top row of plans marks patient heads-of-bed as several points (in red, circled). The second row shows the viewshed from these two points (in blue). The third row, in orange, marks the area visible from the initial blue viewshed and represents the concept of isovist connectivity.

Source: Author's contribution.

behavior mapping to capture patterns of copresence and communication. Copresence is a concept from sociology, and it is focused on how people interact with each other in person (Goffman, 1963; Zhao, 2003). In this study, we gain insight into copresence using behavior mapping. For the purpose of this study, copresence between two or more people is achieved when they are intervisible to each other. Behavior mapping is the non-obtrusive recording of locations and behaviors of the occupants or users of a given location (Barker, 1976). Behavior mapping provides a series of snapshots of behavior in context. Workers in inpatient care teams are highly mobile compared with other kinds of workers, so the traditional practice of evaluating the work environment by the properties of assigned seats is not appropriate to the setting. We used multiple rounds of behavior mapping to develop a general sense of how the care teams distributed themselves in space.

2.3 Characterizing care team communication: SNA

We used methods of SNA to describe nurse communication. While it is possible to directly observe communication in real-time or ask care team members to rate design support for care team communication, these approaches can de-emphasize important ways that the flow of communication is shaped by social, organizational, or physical contexts.

Where one sits in a network of communications shapes the opportunities and constraints of one's access and contributions to the exchange of information. For example, a nurse might have tremendous expertise, but if the nurse only speaks with a few colleagues who also tend to keep to themselves, the nurse's expertise will not be widely shared or used. The functioning of an entire group – such as the care team on an inpatient unit – is affected by the character of its information-sharing network. The structure of the whole network therefore matters for communication flow, as recognized by the SNA community.

SNA is a research method that uses networks and graph theory to gain an understanding of social phenomena (Borgatti et al., 2013). It is increasingly applied to research problems in healthcare for its capacity to describe the quality and function of social relationships in context (Arsenault Knudsen et al., 2024; Patterson et al., 2013). Several studies have used SNA to gain insights into healthcare outcomes, such as hospital-acquired infection (McHaney-Lindstrom et al., 2020; Ueno & Masuda, 2008). Few studies have looked at concrete, fine-grained differences in hospital floorplan layouts and related them to the properties of social networks. Brewer et al. (2018) reported

on inpatient unit SNA and fall rates with respect to the overall shape of units, which is defined using broad types (e.g., radial, cross, racetrack). They found the main effects of floorplan shape and size. In their concluding remarks, they recommended that adding space syntax analysis to the modeling approach might create more precise descriptions of unit layouts. Pachilova and Sailer (2019) found an association between floorplan layout properties and patterns of betweenness centrality among team workers on a per-unit basis. In a related approach, Sailer's (2024) study on routine action networks used space syntax to model the overall environment of outpatient clinics, noting that more open layouts were used in more dynamic ways.

In sum, our conceptual model posits that greater visibility in a space arises from properties of the floorplan layout, which increases the likelihood of a higher density of copresence, which in turn provides the basis for face-to-face communication. This study makes a novel contribution by combining precise measures of inpatient unit floorplan visibility, data on the spatial distribution of care team workers and their communication, and an assessment of communication patterns using social networks.

3. Materials and methods

3.1 Comparative case study approach

This exploratory comparative case study uses space syntax, behavior mapping, and SNA to gain insight into how the design of inpatient units may affect care team communication. Specifically, we expect two kinds of findings. First, we expect to find quantitative differences between the visibility properties of the two units. Second, we expect to find indicators of more communication in the more visually open unit. The specific measures are described in the sections below, after a brief description of the hospital settings. Specific expected findings are outlined at the end of the description of each of the three methods: space syntax, behavior mapping, and SNA. The method for this study was approved by Institutional Review Boards at Texas Tech University and Indiana University.

3.2 The hospital settings

This study compares two 32-room hospital inpatient units with identical floorplates that are located one over the other in Indiana University West Hospital, a community

hospital campus located in suburban Indianapolis. The MSU is part of the original 2004 building, while the AAU was begun in 2017 as part of a vertical tower expansion that opened in 2020. The two units have highly similar layouts, including similar patient room layouts, as the footprint and many vertical elements were already fixed at the start of the design. A main design difference is that the newer AAU was designed to be more visually open with four, spacious team nurse stations in addition to decentralized stations and two staff-only corridors that traverse the core, while the older MSU is more visually enclosed, has one large team station, relies primarily on decentralized nurse stations, and has one staff-only corridor that traverses the core (Figure 2).

The patient rooms are highly similar in size and layout across the two units, and rooms on both units can act as acuity adaptable rooms (i.e., that can accommodate patients with a diverse variety of care needs). The units have a symmetrical shape and layout, and they are mainly accessed by staff and others through the west corner of the unit (plan left), where the unit secretary and the charge nurse typically sit. The eight patient rooms nearest each major corridor crossing constitute the four functional sub-areas of each unit. Both units have decentralized nurse

stations near all patient rooms. All the patient rooms on the MSU and eight of the rooms at the four stub corners of the AAU have corridor side windows to patient rooms. The blinds to these windows to the patient rooms are typically closed, unless there is a specific risk of patient harm (e.g., a high fall-risk patient). The AAU had been operating for more than 2 years when data were collected for this study. Additional unit details are outlined in Table 1.

3.3 Space syntax methods

Space syntax methods capture visibility properties of environments-as-perceived from floorplans using precise, quantitative measures. In nursing units, visibility is recognized as impacting both the quality and safety of patient care (Choi, 2011; Ossmann et al., 2019; Ossmann, 2022) and dimensions of healthcare work (Cai & Zimring, 2012; Lu & Zimring, 2011; Pachilova & Sailer, 2019; Pachilova & Sailer, 2022; Zook et al., 2024). We focus on dimensions of the layouts that are expected to relate to the work of care teams.

Between units, we compare the average viewshed size and average integration for the entire unit floorplan, as

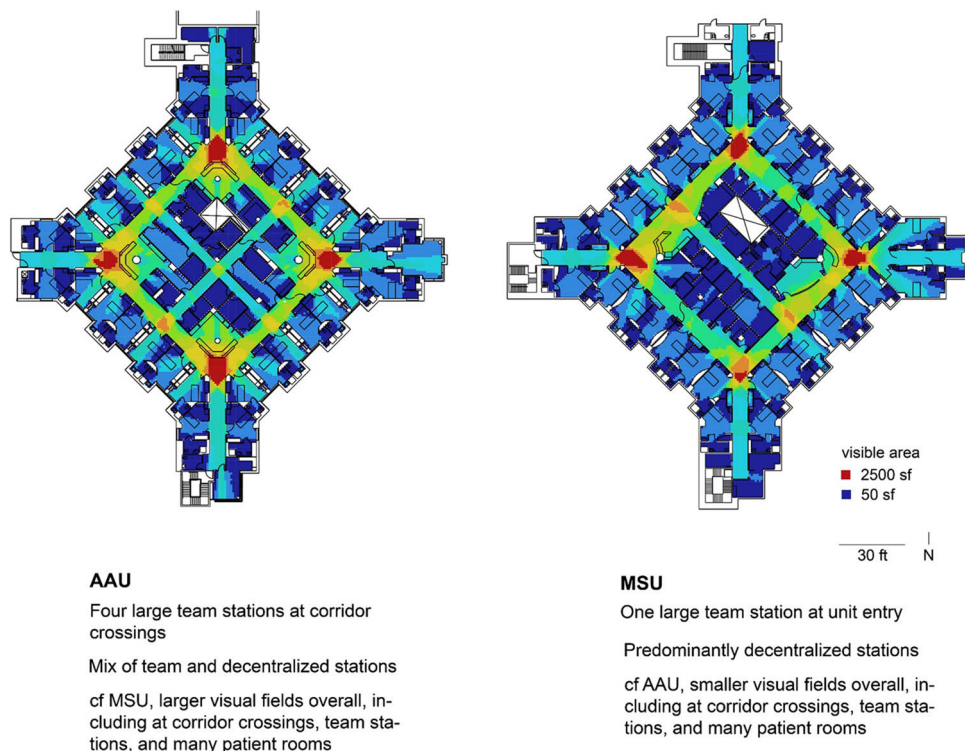


Figure 2. Annotated diagrams of the two inpatient units with color-coded viewshed sizes. Note: red indicates larger viewsheds, while blue indicates smaller viewsheds. AAU, acuity adaptable unit; MSU, medical-surgical unit.

Source: Author's contribution.

	AAU Progressive, medical surgical	MSU Medical surgical
Staffing		
Day staffing ratio	4 patients:1 nurse	5 patients:1 nurse
Night staffing ratio	4 patients:1 nurse	6 patients:1 nurse
Additional staff to nurses and patient care assistants	Unit secretary (day) Monitor technician Transport nurse	Unit secretary (day)
Supports for communication		
Team nurse stations (w/ fixed workstations)	4	1
Decentralized nurse stations (w/ fixed workstations)	20, single seat	18, two seats each
Badge-based communications device	Yes	Yes
Staff-only corridors through core	2	1

AAU, acuity adaptable unit; MSU, medical-surgical unit.

Table 1. Nursing unit attributes.

Source: Author's contribution.

well as the average isovist connectivity values of the team and decentralized nurse stations. Although the behavior mapping only occurs in the main corridor that rings each unit, the spatial properties of the corridor are ultimately shaped by visual relationships with the rest of the unit. We therefore analyze the continuous space of the entire unit, excluding chases, public bathrooms, stairwells, structural elements, and fixed furniture taller than 5'0".

Viewshed size is calculated as the area of the 360° view for each point on a grid that covers the floorplan (technically, centroids of cells in a grid), based on a spacing of 1 sq ft. Viewshed size is a direct measure of visual openness, with larger values denoting a more visually open environment. We report viewshed size in square feet. Mean depth assesses how much of the plan must be traversed between one location and another, calculating the average from each location to every other location. In a visibility graph analysis (VGA) approach, the units traversed are viewsheds. The lower the VGA mean depth of the unit, the more visually interconnected the space of the unit is. In the empirical literature, more integrated spaces (which are characterized by lower mean depth) are associated with greater rates of unplanned encounters in workplaces

(Grajewski, 1993; Penn et al., 1999), underscoring the potential relevance of integration to care team communication.

Isovist connectivity is a space syntax measure that describes the visual exposure of a prespecified origin in a way that characterizes how the origin relates to the rest of the floorplan (Ossmann et al., 2019; Ossmann, 2022). Ossmann et al. (2019) and Ossmann (2022) developed isovist connectivity to capture the capacity of nurses to surveil intensive care unit patients while remaining visually connected to the unit environment as a whole. Given an origin, isovist connectivity first sums the area visible from each of the points in that origin. A viewshed is drawn for the origin, and the area visible from each point of this viewshed is added to the initial sum. The average of these values is the isovist connectivity for the origin (Figure 1). For each unit, we assessed isovist connectivity using team and decentralized nurse stations as origins. The three syntax measures give us a sense of overall visual openness (average viewshed size), a sense of the degree to which the unit is visually unified and interconnected (average integration), and a sense of the degree to which nurse stations are visually exposed and embedded into the floorplan layout (isovist connectivity of nurse stations).

The calculation of each measure, taken in DepthmapX (DepthmapX Development Team, 2017), is based on a floorplan prepared as a computer-aided design file. Viewshed sizes were calculated in Depthmap using the measure *connectivity*. For integration, we use the normalized measure *visual mean depth*. The mean depth analysis was run atop the initial viewshed size analysis and used the same modeling conventions. Isovist connectivity was assessed using a step depth function from each origin to calculate the relevant viewshed size values and then take averages from the associated table of values.

For each measure, we test for statistically significant differences between units. Decentralized and team stations are conceived as a system of locations that work together to support care team work and are pooled for the between-unit comparison of average isovist connectivity values.

We expect the AAU to have greater average viewshed size, higher average integration, and higher average isovist connectivity of nurse stations.

3.4 Behavior mapping

In this study, behavior mapping is intended to describe patterns of copresence. The behavior mapping technique unobtrusively records the locations and actions of the

	AAU	MSU
Day 1		
Staff	17	14
	10 RNs	8 RNs
	3 PCAs	5 PCAs
	1 sitter	1 unit secretary
	1 unit secretary	
	1 monitor technician	
	1 respiratory therapist	
Census	27	32
Nurse–patient ratio	1:2.7	1:4
Day 2		
Staff	15	14
	8 RNs	9 RNs
	3 PCAs	4 PCAs
	1 sitter	1 unit secretary
	1 unit secretary	
	1 monitor tech	
	1 resp therapist	
Census	26	30
Nurse–patient ratio	1:3.25	1:3.33

AAU, acuity adaptable unit; MSU, medical-surgical unit; PCAs, personal care assistants; RNs, registered nurses.

Table 2. Staffing and census on behavior mapping days.

Source: Author's contribution.

users in a setting (Barker, 1976). A single investigator walked a predetermined route through the main corridor

of each unit on an alternating basis over 2 days and recorded the locations of care staff as they passed or were passed by the investigator's coronal plane. For each observation, the investigator noted if in-person communication was taking place. No identities or speech contents were recorded. A total of 32 rounds (16 on each unit) were completed, spanning the 7 a.m. to 7 p.m. shift. Details of staffing and census on observation days are shown in Table 2. Two sample behavior maps are shown in Figure 3.

We processed the behavior mapping data by dividing each unit into quadrants that correspond to the functional quadrants of each unit. Understanding how nurses distribute themselves on a per-quadrant basis within the overall unit can help us understand how they use the space to cope with the competing pressures to be near the patient's bedside while also remaining attached to the rest of the care team. We then compared the average per-day density of care team workers (per 1,000 ft²) for each quadrant, surmising that an uneven density between a unit's quadrants may be less conducive to the flow of information. We calculated densities for two groups: one of care team workers present, and one of the subset of care team workers present who were talking. Densities present convey how the care team was distributed in space across functional, but not physical boundaries; densities talking conveys how much those present are engaging in face-to-face communication. We look at differences in the density of care team workers between quadrants within each unit. We also calculated ranges for the most and least dense quadrants for both presence and talking on each unit.

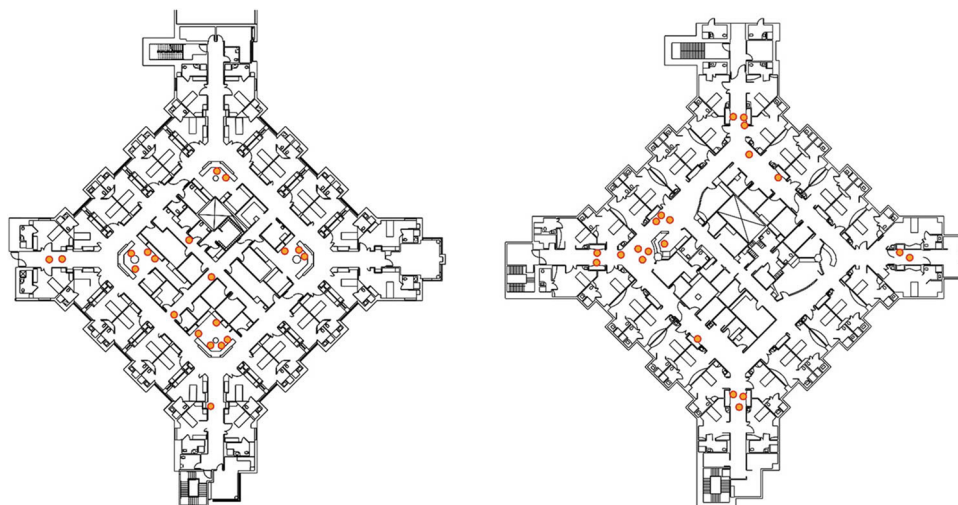


Figure 3. Sample behavior maps. Note: In these behavior maps, dots mark the locations of members of the care team observed during a behavior mapping session in the AAU (left) and MSU (right). Both maps were taken near noon on the same day. AAU, acuity adaptable unit; MSU, medical-surgical unit.

Source: Author's contribution.

We expect the AAU to have higher densities of communication overall and for quadrant density values to be more even (i.e., that the care team will spread more evenly across the more integrated and visible unit).

3.5 SNA

Unit care staff, mainly licensed and unlicensed nursing personnel, working on the AAU and MSU were asked to complete paper-based questionnaires at the end of the 12-h day shift over 3 weekdays. The shifts were selected to capture as many unique care staff as possible with minimal overlap. The questionnaire forms listed other care team members on the just-completed shift and asked each respondent, “How often did you discuss patient care with each of these individuals face-to-face while working on your unit during the current shift?” Response options were as follows: “never,” “rarely,” “sometimes,” “frequently,” and “constantly.” The questionnaire items were adapted from Brewer et al.’s (2018) information-sharing network survey for care teams. The questionnaire also contained demographic questions about experience, education, and employment type and duration.

The social network questionnaire was distributed by an Indiana University Health team member at the end of the shift for care team members to complete. Completed questionnaires were conveyed to the principal investigator for analysis. Each participant’s name was recoded based on role (e.g., “RN-7”), and questionnaire responses were converted to a numeric scale.

We evaluated two main SNA measures. *Network density*, a whole network measure, characterizes the degree to which a network approaches the condition of all-talk-to-all. Practically speaking, network density is a measure of communication cohesion within a given setting. Low network density indicates that people are generally talking to few others, while a maximally high network density value of 100% means that each person talks to every other person. Together with network density, we report total *ties*, which denote the number of questionnaire responses reporting a communication event. A response was considered a tie if either or both individuals in a dyad reported talking to the other about patient care. However, as ties are not normalized with respect to the size of the network, we do not discuss them further.

Indegree characterizes the average number of incoming communications for an individual. Indegree is taken to reflect influence or importance, in that it conveys how often one is sought out for communication. In addition to reporting per-unit indegree, we report differences in indegree by two main care team worker types: registered nurses

(RNs) and personal care assistants (PCAs, sometimes called nursing assistants). Few studies have paid attention to the nature of relationships between PCAs and other healthcare workers (for an exception, see Campbell et al. (2021)).

SNA density and indegree were calculated for each of the survey days on the AAU and MSU in UCINET (Borgatti et al., 2002). We report values both for any communication and for communication that is frequent or constant. We report on SNA using descriptive statistics (Knoke & Yang, 2021) and provide sociograms to depict social networks.

We expect network density values to be higher on the AAU. The indegree analysis was intended to provide insight into communication differences between RNs and PCAs; it is wholly exploratory, and we have no specific expectations.

4. Results

4.1 Space syntax results

4.1.1 Visibility (viewshed size)

We compared viewshed size between units using an unpooled two-sample *t*-test assuming unequal variances. The AAU had, on average, larger viewsheds in square feet ($M = 699$; $SD = 585$) than the MSU ($M = 608$; $SD = 531$), and this difference was statistically significant (for Welch’s test, $F_{254, 1} = 15.9$, $p < 0.0001$). Figure 4 shows the quantile values of viewshed sizes. The MSU’s largest value is near the glass meeting room and the corridor intersection at the right of the plan. For the AAU, the largest values occur near each of the four nurse stations. For both units, the 75th-percentile values characterize minor corridors, and lower values occur in each unit’s various enclosed rooms.

4.1.2 Mean depth (integration)

By comparing mean depth between units, an unpooled two-sample *t*-test assuming unequal variances showed that the AAU had statistically significantly lower mean depth ($M = 3.34$; $SD = 0.61$), indicating greater integration of viewsheds on the AAU compared with the MSU ($M = 3.48$; $SD = 0.61$): (for Welch’s test, $F_{457, 1} = 21.4$, $p < 0.0001$).

4.1.3 Isovist connectivity of nurse stations

We compared isovist connectivity values of all nurse stations on a per-unit basis using an unpooled two-sample *t*-test assuming unequal variances. The system of team and

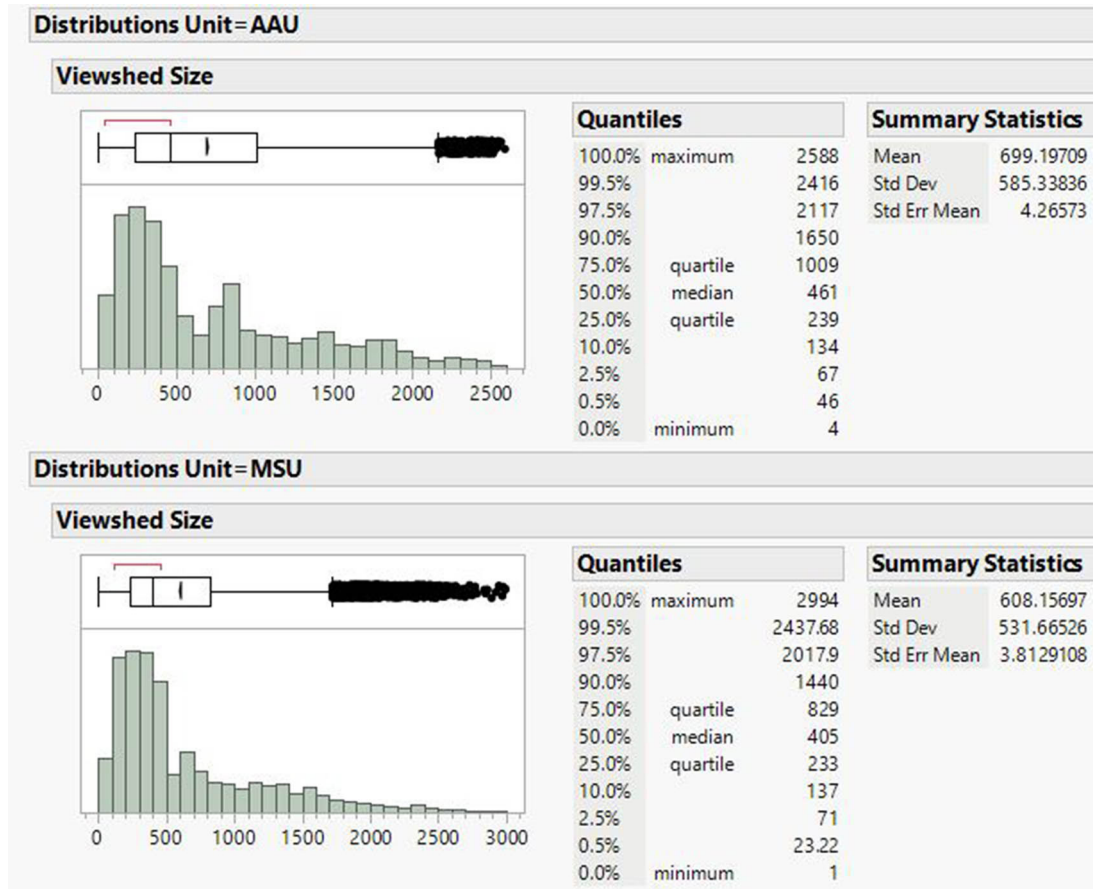


Figure 4. Histograms of viewshed sizes for the AAU (upper) and MSU (lower). AAU, acuity adaptable unit; MSU, medical-surgical unit. Source: Author's contribution.

decentralized nurse stations on the AAU had slightly larger isovist connectivity values ($M = 1,280$; $SD = 220$) than the MSU ($M = 1,269$; $SD = 189$). However, this difference was not statistically significant.

4.2 Behavior mapping results

Between units, more care team workers were observed on the MSU (353 observations) than on the ASU (324 observations), but a greater proportion of care team workers on the ASU were observed talking (46%) compared with the MSU (33%). For both units, the west nurse station, where the unit entry is located, had a statistically significantly higher density of care team workers present and talking than the other three quadrants. The west quadrant of the AAU had higher presence density and talking density than the other three quadrants. The MSU values similarly had significantly higher densities in the west quadrant both for presence and talking.

We also compare the range of densities across quadrants within each unit. We began by calculating the total 2-day average of observations for each quadrant area and normalizing (dividing) by 1,000 ft². We subtracted the lowest quadrant value on the unit from the value for the west quadrant, which was always the quadrant with the highest value. Within the AAU, the range of the mean densities among the quadrants was smaller for density present (range = 25.81) and density talking (range = 18.86). The range values for the MSU were higher at 37.76 for presence and 20.41 for talking. This indicates that although both units polarized density and talking at the west, where the unit entry was located, the AAU had a more even spread of care team workers present and talking across the rest of the unit than the MSU did (Figure 5 and Table 3 for average values by quadrant).

4.3 SNA results

For the SNA results, most of the individuals who participated were RNs (62%), followed by PCAs (30%), with other

members of the care team, like unit secretaries and monitor technicians, making up the remainder (8%).

SNA typically aims to capture information from 100% of a clearly defined population, in our case, care staff on a day shift for a specific inpatient unit. One of the surveys had a response rate of <50%, which was a threat to the validity of the subsequent findings. The low-response survey was discarded for the MSU, and a survey for the AAU was discarded based on random choice, so that the analysis reported here is based on two surveys per unit. The response rates for the surveys reported are 71% (AAU

day 1), 86% (AAU day 2), 64% (MSU day 1), and 54% (MSU day 2). Over the days studied, the ratio of RNs to PCAs was very similar if not identical for the two units (Table 4 for questionnaire respondent attributes).

For the AAU, network densities for any degree of discussion of patient care (i.e., responses other than “never”) on data collection days 1 and 2 were 77 and 70%, yielding an average density of 73%. For the MSU, network densities on data collection days 1 and 2 were 66 and 55%, which is an approximate average density of 60.5%. On average, every respondent was in contact with 73% (AAU) or

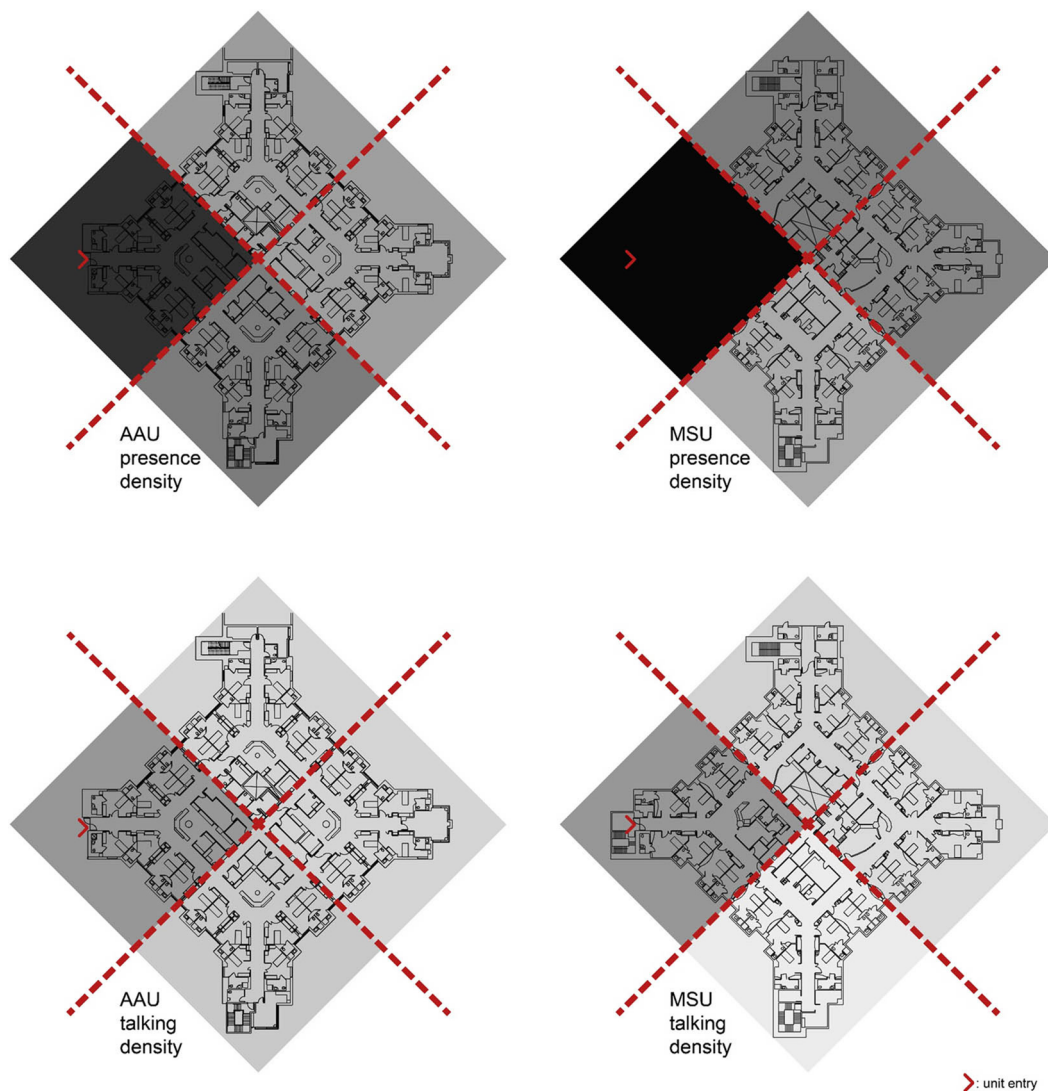


Figure 5. Densities of presence and talking by quadrant on each unit. *Note:* In these density maps, a darker tone represents higher observed densities of care team workers. The top row shows the density of care team workers present, and the bottom row shows the density of care team workers talking. The left column is the AAU and the right column is the MSU. Both units have densities concentrated toward the entry (left quadrant), with the AAU showing a more even distribution of care team workers across the unit. AAU, acuity adaptable unit; MSU, medical-surgical unit.

Source: Author's contribution.

	AAU	MSU
Percent observations with communication	46%	33%
	324 observations	353 observations
	149 yes; 175 no	115 yes; 238 no
Presence density, 2-day average normalized per 1,000 ft²		
West quadrant	48.72	57.76
North quadrant	23.29	30.69
East quadrant	22.91	28.49
South quadrant	30.8	20
Range (max–min)	25.81	37.76
Talking density, 2-day average normalized per 1,000 ft²		
West quadrant	27.5	24.23
North quadrant	8.64	11.16
East quadrant	8.65	7.22
South quadrant	11	3.82
Range (max–min)	18.86	20.41

AAU, acuity adaptable unit; MSU, medical-surgical unit.

Table 3. Average presence density and talking density by quadrant.

Source: Author's contribution.

60.5% (MSU) of their colleagues during their shift. For both units, networks are dense, which is consistent with the information- and communication-rich nature of inpatient care. Sociograms show the density of the any-communication network on day 1 of each unit (Figure 6).

For communication that was characterized by “frequently” or “constantly,” the AAU network densities on data collection days 1 and 2 were 35 and 34% with an

	AAU	MSU
Day 1		
Participants	12 of 17 on shift	9 of 14 on shift
Response rate	71%	64%
RNs	8 of 12 on shift	7 of 10 on shift
PCAs	2 of 4 on shift	1 of 3 on shift
Other care team workers	1 of 1 on shift	1 of 1 on shift
Shift PCA-to-RN ratio	1:3	1:3.3
Day 2		
Participants/Total	12 of 14 on shift	7 of 13 on shift
Response rate	86%	54%
RNs	9 of 10 on shift	6 of 8 on shift
PCAs	3 of 3 on shift	1 of 4 on shift
Other care team workers	2 of 2 on shift	0 of 1 on shift
Shift PCA-to-RN ratio	1:2	1:2

AAU, acuity adaptable unit; MSU, medical-surgical unit; PCAs, personal care assistants; RNs, registered nurses; SNA, social network analysis.

Table 4. SNA questionnaire respondent attributes.

Source: Author's contribution.

overall average density of 34.5%. For the MSU, network densities on data collection days 1 and 2 were 17 and 19% with an overall average density of 18%. The AAU evidences greater network density for both communication conditions studied, with a greater relative difference for the frequent or constant communication network (Table 5 for a summary of network density data).

Moving to the SNA indegree, care team workers on the AAU were cited as being sought out for patient care-related communication more frequently than care team workers on the MSU, both for any degree of communication and for frequent/constant communication. The indegree findings are consistent with the findings on network density.

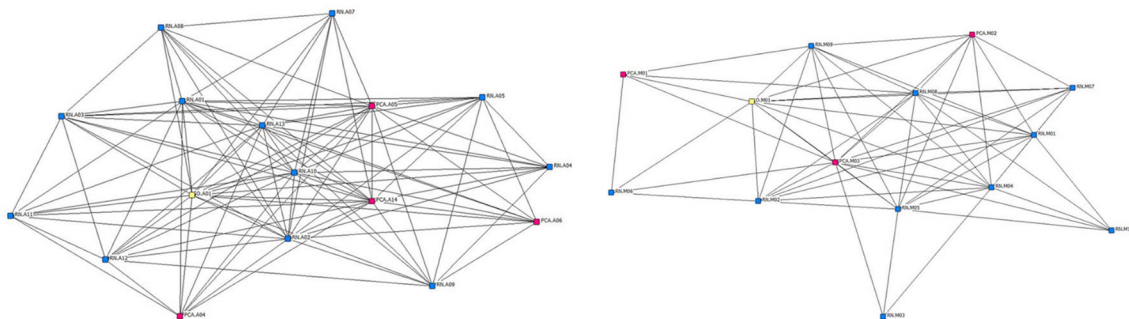


Figure 6. Sociogram of network density for any patient-related communication. *Note:* In these sociograms of network density, the AAU appears on the left and is a denser network. The less-dense MSU network is on the right. Blue nodes represent RNs, pink nodes represent PCAs, and yellow notes represent other care team workers. AAU, acuity adaptable unit; MSU, medical-surgical unit; PCAs, personal care assistants; RNs, registered nurses.

Source: Author's contribution.

Any communication Re patient care		
	AAU	MSU
Day 1		
Density	76%	66%
Total ties	208	120
Day 2		
Density	70%	55%
Total ties	128	86
2-Day average		
Average density	73%	60.5%
Average total ties	188	103

Frequent/constant communication Re patient care		
	AAU	MSU
Day 1		
Density	35%	17%
Total ties	96	30
Day 2		
Density	34%	19%
Total ties	62	30
2-Day average		
Average density	34.5%	18%
Average total ties	79	30

AAU, acuity adaptable unit; MSU, medical-surgical unit.

Table 5. Network density and total ties.

Source: Author's contribution.

When we break it down by job type, we find that average indegree values for RNs and PCAs are roughly

similar on the AAU, while on the MSU, the average PCA indegree is equal to or higher than the average RN indegree. On the AAU, average indegree values for any communication with RNs were 8.3 (day 1) and 7.6 (day 2). In practical terms, this means that a mean of 8.3 care team workers cited speaking to an RN about patient care on day 1 and 7.6 people did so on day 2. For PCAs on the AAU, average indegree values were 8.8 (day 1) and 7 (day 2). On the MSU, average indegree values for RNs were 5.4 (day 1) and 3.1 (day 2). For PCAs on the MSU, average indegree values were 6.3 (day 1) and 5.5 (day 2). The average PCA indegree is notably higher than the average RN indegree on the MSU.

For frequent or constant communication on the AAU, average RN indegree values were 3.1 (day 1) and 3.2 (day 2), whereas for PCAs, average indegree values for frequent or constant communication were 3.7 (day 1) and 3.2 (day 2). Again, the values for RNs and PCAs on the AAU are similar on the AAU. On the MSU, average RN indegree values for frequent or constant communication were 1.3 (day 1) and 3.1 (day 2), while for PCAs, the corresponding values were 1.3 (day 1) and 5.5 (day 2). Indegree for PCAs is the same or higher than for RNs on the MSU. Sociograms show the indegree of communication characterized as “frequently” or “constantly” on day 2 on both units (Figure 7).

We calculated ratios of average PCA indegree to average RN indegree and found that for any communication on the AAU, the ratio of PCA-to-RN indegree is 1:1.02, a roughly equal value. For any communication on the MSU, the ratio is 1:0.71, representing a notably higher average indegree value for PCAs compared with RNs.

When we look at the networks of frequent or constant communication about patient care, the ratio of average

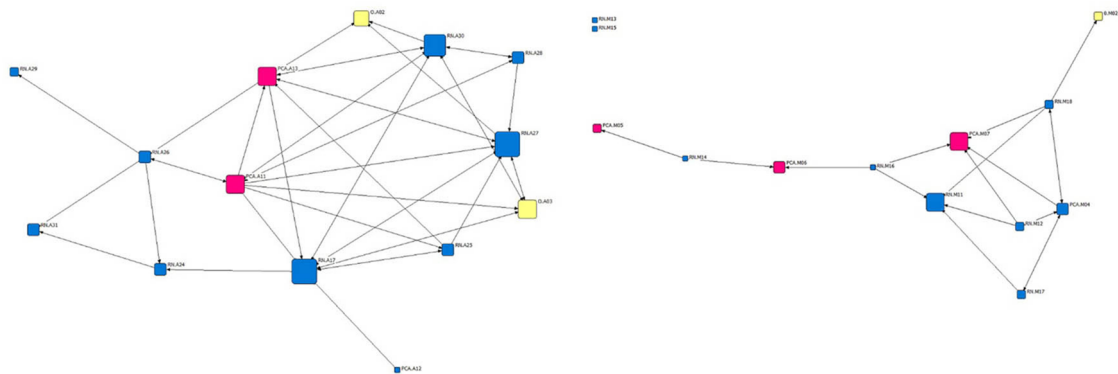


Figure 7. Sociogram of indegree for frequent or constant patient-related communication. Note: In these sociograms of indegree, the AAU appears on the left and MSU is on the right. The size of each node reflects the indegree value, with large nodes corresponding to higher indegree. Blue nodes represent RNs, pink nodes represent PCAs, and yellow notes represent other care team workers. Note that in the MSU sociogram, two RNs are isolates. AAU, acuity adaptable unit; MSU, medical-surgical unit; PCAs, personal care assistants; RNs, registered nurses.

Source: Author's contribution.

indegree values of PCAs to RNs on the AAU falls to 1:1.14, while on the MSU it remains a relatively high 1:0.78. Table 6 shows a summary of all indegree values.

5. Conclusion

5.1 Summary

This study compared design and care team communication on two inpatient units with data collection methods that corresponded with a conceptual framework wherein patterns of visibility enable patterns of copresence, which in turn affect patterns of communication.

We found that the AAU, which was designed to promote care team connections, has statistically significantly

larger and more integrated viewsheds. The system of nurse stations on the AAU had higher isovist connectivity values, indicating more visual exposure and more robust visual connection between the nurse stations and the rest of the unit on the AAU, even though the isovist connectivity differences were not statistically significant.

For both units, more care team worker presence and talking were observed in the west quadrant of the plan, at the unit entry. This portion of the layout, which hosts the main unit entry, is most strongly programmed for presence. On both units, this location hosted a large team nurse station, which is the only large team station on the MSU. On the AAU, large team stations are spread across the unit. The AAU had smaller differences between the quadrants with the highest and lowest presence and talking densities, indicating a somewhat more even spread of the care team across the unit. On the MSU, copresence and talking were more concentrated in the west, with very low densities in the south and intermediate densities in the north and east. This lends preliminary support to the idea that care team staff distribute themselves across the unit more evenly when the space of the unit is more integrated and there is both more visibility in general and more visibility at team work areas in particular. They are thus more able, it would seem, to cope with the competing pressure to be close to the patient while maintaining contact with the greater care team.

The AAU had higher communication density and average indegree both for networks denoting any communication and networks denoting frequent/constant communication. Indegree values for frequent/constant communication revealed that PCAs were often sought out for patient-related communication about as much if not more than RNs. The PCAs on the MSU, where communication networks were comparatively sparse, usually had higher average indegree than RNs, and they sometimes acted as bridges that prevented the network from fragmenting. An interesting and unexpected insight of this study is that where inpatient communication networks are sparse, the role of the PCA may become especially important. The higher PCA engagement in the MSU could also have to do with the lower acuity of the patients; with lower acuity patients, PCAs may have more autonomy to provide a greater portion of patient care and engage in related cross-team communication.

6. Discussion

Care team communication is important for patient care. In this case, members of the care team specifically requested

Any communication Re patient care		
	AAU	MSU
Day 1		
RN average indegree	8.3	5.4
PCA average indegree	8.8	6.3
PCA:RN indegree (ratio)	1:0.94	1:0.86
Day 2		
RN average indegree	7.6	3.1
PCA average indegree	7	5.5
PCA:RN indegree (ratio)	1:1.09	1:0.56
2-Day average		
PCA:RN indegree (ratio)	1:1.02	1:0.71
Frequent/constant communication Re patient care		
	AAU	MSU
Day 1		
RN average indegree	3.1	1.3
PCA average indegree	3.5	1.3
PCA:RN indegree (ratio)	1:0.89	1:1
Day 2		
RN average indegree	3.2	3.1
PCA average indegree	2.3	5.5
PCA:RN indegree (ratio)	1:1.39	1:0.56
2-Day average		
PCA:RN indegree (ratio)	1:1.14	1:0.78

AAU, acuity adaptable unit; MSU, medical-surgical unit; PCA, personal care assistant; RN, registered nurse.

Table 6. PCA and RN indegree.

Source: Author's contribution.

a design that would support greater ease of intra-team connection, which the design team responded to by creating a more visually open unit with large, evenly distributed spaces for care team members to work together.

This study compared design and care team communication on two inpatient units following a conceptual framework wherein patterns of visibility affect patterns of copresence, which in turn affect patterns of communication. Data from the two inpatient units were consistent with the conceptual framework, with the more visually open unit having a more even spatial distribution of care team workers, who verbally communicated with one another more frequently, as observed by behavior mapping and as self-reported through the SNA questionnaire. It should be said that nursing staff can and do routinely overcome designs that make it difficult to, for example, stay close by a high-risk patient. Nevertheless, designs that are congenial to such purposes may ultimately make it easier, and thus more likely, for care teams to provide quality, safe patient care.

	AAU	MSU
Visibility values		
Avg. viewshed size, unit	699 ft ^{b*}	608 ft ^b
Avg. mean depth, ^a unit	3.34*	3.48
Avg. isovist connectivity, nurse stations	1,280 ft ^b	1,269 ft ^b
Behavior mapping values		
Percent observations with communication	46%	33%
Quadrant range (max–min) for presence density	25.81	37.78
Quadrant range (max–min) for talking density	18.86	20.42
SNA values		
Average network density, any communication	73%	60.5%
Average network density, frequent/constant communication	34.5%	18%
PCA-to-RN indegree ratio, any communication	1:1.02	1:0.71
PCA-to-RN indegree ratio, frequent/constant communication	1:1.14	1:0.78

^aMean depth (Hillier & Hanson, 1984) is the measure of integration used.

^b $p < 0.0001$.

AAU, acuity adaptable unit; MSU, medical-surgical unit; PCA, personal care assistant; RN, registered nurse.

Table 7. Summary of key values.

Source: Author's contribution.

Healthcare design professionals – such as planners, architects, and interior designers – should consider the apparent capacity of greater openness to promote copresence and communication. On inpatient units, such openness can be pursued by designing wider corridors, including larger and/or a greater number of team nurse stations that are spread across the unit, and routing corridors through the core, among other strategies that design the corridor as a space for knowledge work (Table 7 for a summary of key values).

While we have found each link of the conceptual model to affirm the importance of unit visibility conditions to care team communication, the cross-sectional nature of the study precludes claims of causality. To construct a study that models causality, we would need a larger sample of inpatient units, where floorplan layout attributes differ, but other aspects, such as acuity and organizational factors, could be matched or statistically controlled for. This article contributes to the case that such a study would be valuable.

Other limitations merit discussion. In hospital environments, operational conditions, such as licensure rates, likely count for more than designed conditions in most normal cases. Both units serve medical-surgical patients, but the AAU also provides care to progressive care patients. While the AAU hosts more care team communication, the higher acuity of the AAU patients likely drives some of the differences in communication patterns.

An additional limitation arises from differences in response rate by unit. Not only were all questionnaire response rates <100%, but there were also differences in response rates between units, with a lower percentage of MSU care team workers completing the questionnaires. Although the indegree and density measures were selected in part to dampen the effects of <100% response rates, missing responses and differences in response rates between units could have impacted the patterns of communication that we have described.

The study generated some new insights on PCAs. PCAs tended to be cited in as many or more patient care-related communications as other care staff, and they likely hold greater stores of information and knowledge than commonly receives explicit attention in the research literature. Above and beyond this, PCAs appear to sometimes act as the informational bridges that hold sparse communication networks together. This is consistent with previous studies that found reductions in work role hierarchy when care teams were strained by absences (Pachilova et al., 2017). PCAs as an occupational group may not have been given due attention in the research literature to date, and future research projects might valuably correct this oversight.

This article contributes to SNA scholarship in two ways. First, we find notable value in whole network analysis – here, as network density – although such approaches are not predominant in SNA scholarship. Density is a comparatively reliable measure (Marsden, 1993), and it is readily useful for using network structure to better understand the activities of a group or organization, as distinct from a focus on discovering the properties of networks themselves (Sarkar et al., 2010). We find density useful in our cross-disciplinary study, where the primary focus is on discovering built environment conditions that support group communication, and not on network properties as such.

Second, we add to the body of scholarship that highlights the importance of context to social networks. Social facts occur in locations, and even fine-grained and highly localized differences between one place and another are associated here with differences in emergent social behavior. Our detailed account of the physical and socio-spatial conditions of social networks has been central to making sense of differences in the properties of communication networks.

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Author contributions

Julie Zook: Conceptualization, Methodology, Formal Analysis, Writing – Original draft preparation, Visualization. Rachel Culpepper: Investigation, Writing – Review & editing. Kerstin Sailer: Methodology, Writing – Review & editing. Chase Miller: Conceptualization, Writing – Reviewing and editing. Jennifer Worley: Conceptualization, Writing – Reviewing and editing.

Conflict of interest statement

The authors state no conflict of interest.

Data availability statement

The participants of this study did not give written consent for their data to be shared publicly, so, due to the sensitive nature of the research, supporting data are not available.

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