Targeted Visibility Analysis in Buildings Ref 068

Correlating Targeted Visibility Analysis with Distribution of People and Their Interactions within an Intensive Care Unit

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Abstract

This is a study of the spatial properties of environments that habitual users of a setting tune their behavior towards. The particular properties under consideration are those that affect visual fields. Previous studies in exhibition and office settings suggest that routine space use is affected by the structure of visual fields. In this study we test the proposition that the impact of spatial organization becomes clearer when we draw a distinction between generic visibility patterns and targeted visibility patterns. In studying generic visibility patterns we are considering all parts of a setting that are visible from each occupiable location. In studying targeted visibility patterns we focus on a previously specified set of visual targets and ask how many become visible from each occupiable location. A script was developed in order to compute targeted visibility measures using Depthmap, which normally computes generic visibility values.

The Neurological Intensive Care Unit (ICU) at a large hospital in Atlanta was chosen as a test setting. Behavioral data were collected by a group of 5 observers over a period of 2 weeks in the 20-bed unit. Each observer recorded the location and activity of all people he/ she saw on the observation sheets while walking through the setting according to a pre-defined path. A total of 46 observation rounds were completed. 946 counts of people were observed in the setting including 320 doctors and 626 nurses.

The targeted visibility measure, which represents number of pre-selected foci that are visible (i.e. patient beds in this case), is more strongly correlated with the density of all staff members compared with standard generic visibility. It is also more strongly correlated with the density of nurses and the density of interacting nurses. Generic visibility is more strongly correlated with both interacting and not-interacting doctors. The finding is all the more consistent because the above mentioned pattern remains unaffected in an additional analysis where all staff members engaging work surfaces were excluded.

The result indicates people with different roles (nurses vs. doctors) are tuned to different features of environment. Nurses, especially when interacting, tend to position themselves where they can have high visual access to multiple patients. The distribution of doctors can be explained by the

preference for a position where they can maximize their awareness of the surrounding environment. With the refinement of the targeted visibility analysis, we can better explain people's spatial choices and routine behaviors. Furthermore, we can draw some important design implications. Designers of healthcare facilities should pay close attention to the structure of visibility in order to address critical issues like communication and interruption, and the transmission of work-related skills and knowledge.

1. Introduction

This study explores how the behavior of a particular category of building users, specifically nurses working at a Neurological Intensive Care Unit at Emory Hospital, is tuned to the spatial properties of the setting. In particular, the study explores how in moving about and in carrying out normal activities, nurses take into account patterns of visibility and occlusion that arise from the arrangement of boundaries. There are good reasons why patterns of visibility are likely to be important to nurses, and therefore registered in the spatial trajectories of their working life. Nurses have to remain continuously aware of the condition of the patients assigned to them even when they move away from the patient room. Visibility provides one critical basis for maintaining contact and awareness.

A growing body of research literature has already established that patterns of visibility influence different kinds of behavior, and some of these studies will be reviewed later. One specific methodological contribution of this study, however, is to propose a refinement of standard analysis of visual fields. In essence, the refinement consists in drawing a distinction between general visibility, that is visibility equally extending in all available directions from each position in a setting, and targeted visibility, that is visibility directed towards a set of pre-selected foci of attention. In this particular case the targets we are interested in are patient beds. It will be shown that targeted visibility, analyzed using an original script developed for this study, correlates with aspects of nurses' behavior much more strongly than general visibility. This finding is all the more interesting because while very clear for nurses does not apply to other categories of users, such as doctors, who have a different role, and hence a different way of registering the setting and tuning themselves to its spatial properties.

1.1 How Is Visibility Defined?

Visibility analysis has a long history in architectural studies. One of the seminal studies is Benedikt's concept of isovist (i.e. the set of all points visible from a given vantage point), and isovist field (i.e. a set of contour lines to represent analytic measures which quantify size and shape of the isovist from all points in the setting) (Benedikt 1979). Benedikt suggests that the isovist field is important to study the behavior and perception; however, he himself did not develop any specific relationship between isovist fields of specific settings and behavioral attributes of people within them.

Later on, many studies developed various measures and computational methods for isovist. Batty (2001) offered a computational scheme for defining isovist and measuring properties of isovist. Turner et al., (2001) used a graph of a grid of points as the isovist-generation location, and calculated the mutual visibility between those points. They introduced measures of a local property, generic visual connectivity, or neighborhood size, and a global property, the mean depth or the mean short path length. Generic visual connectivity represents the set of points that is visible from a location, which can be thought of as equivalent to the area of an isovist. And the mean depth represents the average number of turns that need to be traversed to get from a location to every other points, which is borrowed from Space Syntax theory(Hillier and Hanson 1984).

Besides the isovist, some researchers offered alternative methods to perform visibility analysis. Peponis and his colleagues proposed to partition spaces into a set of convex units based on the appearance or disappearance of visual information about edges, corners, and surfaces (Peponis et al. 1997). The method is called end-point partition or e-partition which is obtained by extending the visibility diagonals which link edges and corners without crossing a wall, in addition to extending all extendible surfaces.

Peponis et al., further developed the measures for individual surfaces according to local and global pattern of visual connectivity between surfaces (Peponis et al. 1998). The two variables are visual connectivity and visual integration. Visual connectivity of a surface is defined as "the number of other surface that sustains a direct or mediated visible relationship with it". Visual integration of a surface is defined as "the number of intervening surfaces that must be taken into account so that we can link it to all the surfaces of a system by a chain of relations of covisiblity".

Later on, "the visual ecological process which occurs between occupant and space" was introduced into visibility theory by Turner (2003) . He demonstrated the movement pattern produced by the process-based agents was well correlated (R2=.67) with the observed pedestrian movement pattern. It is suggested that an understanding of the visual process of inhabitation was crucial to determine the socio-spatial phenomena.

1.2 Behavioral Impacts of Structures of Visibility

Despite the advance in the methodology and its close relationship to visual perception, the application of visibility analysis is limited to a small number of studies. And most of them focus on exhibition settings. For example, Peponis and his colleagues investigated the effect of visibility characteristics of open plan science exhibition on visitor's spatial behavior (Peponis et al. 2004). They found that the contact score (i.e. demonstrable visitors' awareness of exhibits indicated by observed proximity between the exhibit and visitors' paths) of individual free-standing exhibits was associated with their visual accessibility (i.e. the generic visual connectivity and the mean depth), The active engagement (i.e. recorded interaction between visitors and exhibits) is associated with cross-visibility of individual exhibits, which represents the number of exhibits that can directly see this exhibit, fully or partially.

Tzortzi (2005) found that the visibility characteristics of display layout influenced the visitor's exploring patterns by comparing two museums. In one museum, paintings were symmetrically arranged at the end of vistas and are confronted frontally. The repetitive perspective vistas through spaces, eliminated the sense of self-exploration. In the other museum, objects were revealed "through a succession of diagonals". The gradually changing of vistas through spaces prolonged the sequential experience and enhances the sense of self-exploration. Hillier & Tzortzi (2006) reported that the average density of movement traces of 100 Tate Britain gallery's visitors in each space was highly correlated with the average visual integration (i.e. the standardized mean depth) of all points in that space (R^2=.68).

There are very few empirical studies outside the exhibition setting. One of them is based on the office setting (Peponis et al. 2007). The authors compared the visibility characteristics of the new and old office setting for the same organization, by analyzing visual connectivity and visual integration. The workspaces in the new premises were visually more integrated and egalitarian than those in the old. These properties generated "intensified awareness and cognitive opportunity" in the new office.

1.3 Methodological Extensions of Visibility Analysis

The applicability of visibility analysis to studies of the behavioral impacts of buildings can be enhanced by extending the methodologies applied in visibility analysis. In most studies, all occupiable and visible points on a setting are equally taken into account as potential origins and destinations of lines of sights.

However, in real life, some locations weigh more than others when people deploy themselves or move around, especially in the settings where view control, privacy is an issue. It is a natural tendency for an observer to perceive and pick up important visual information that is relevant to his or her intention. We take the proposition that the visual features in environment that are related to habitual users are memorable and salient, which can therefore influence and be registered in individual's subsequent spatial behavior. Thus, our scheme of visibility structure consists in visibility directed towards a set of pre-selected foci of attention, which is named as ‘targeted visibility' here.

Empirical studies support that visibility towards salient components in the environment can influence wayfinding performances and open exploration patterns.

Braaksma and Cook (1980) developed a quantitative measure to evaluate the ease of wayfinding in airport terminals. The measure is based on the matrix of visual accessibility between locations. The visibility index is a global measure which represents the ratio of the number of available sight lines and the total number of possible sight lines. A relationship was found between the visibility index and self-reported difficulty in wayfinding in 10 airports. Locations with low visibility from other locations were reported to more difficult to find than those with high visibility.

Several follow-up studies further fine-tuned the measure of visibility index for airport settings. Lam and others (2003) proposed a modified visibility index, which is the ratio of the number of available sight lines and the total number of sight lines that should exist within the airport. They believed that not all units are related to each other and may need to be accessed in sequence. Therefore, only the relevant sight lines within the network were considered. Churchill and others (2008) extended the measure by incorporating the number of decision points and level changes.

By studying the wayfinding performances of 14 people in simulated virtual town, Omer and Goldblatt (2007) found that a high degree of overlapping between the visual fields of an origin and a target landmark, which measured by the number of common visible landmarks, improved wayfinding performances.

Empirical studies also showed that visibility towards specific objects (i.e. art objects and individual exhibits) is critical for visitor's exploring pattern in museum and exhibition settings (Tzortzi 2005; Peponis et al. 2004). However, earlier studies have not developed any automated analytical tools deals with visibility patterns directed towards specific destinations within an environment. Peponis and his colleagues (2004) for example, have manually constructed the graph of display cross-visibility.

Markhede and Carranza (2007) proposed an automated model, named 'spatial positioning tool' to measure the visual relationship among selected positions using Java language. The tool can produce both the inter-visibility graph and integration graph using a selection of points as original points of isovist. Markhede and Koch (2007) argued that analyzing a selection of organized positions integrates social structures into the visibility analysis. The face-to-face interaction in offices was strongly correlated with the visibility measures among selected positions.

Unlike Markhede and others' model which focuses on visual relationship among selected positions, our visibility model deliberately separates the origins and destinations of lines of sights. In other words, not all potential occupiable spaces are equally considered as targets of visibility, and vice versa, for both theoretical and practical reasons. The conceptual development of targeted visibility is grounded on Gibson's theory of visual perception, mainly his argument of affordances. For Gibson, the relationship of human and environment is reciprocally defined through affordances, which are what the environment offers, provides or furnishes, either for good or ill (Gibson 1979). They are the functionally significant properties of the environment in respect to a particular individual. Gibson further suggests that the information about affordances that an environment provides can be picked up directly. As he said: "The perceiving of an affordance is not a process of perceiving a value-free physical object to which meaning is somehow added…it is a process of perceiving a value-rich ecological object... Physics may be value-free, but ecology is not (Gibson 1979)." Therefore, for a given individual, certain environmental properties are functionally more significant than others, and those properties can be directly perceived. Consequently, the visibility analysis should focus certain visual features in environment that are more related to habitual users. From practical perspective, the relationship of origins and destinations of lines of sights are not always reciprocally defined. In simple words, in the situation that people A can see people B, B sometime can not see A, because of illumination, surrounding context, orientation of views etc.

Thus, we introduce the targeted visibility analysis, one that tunes to specific features and one that has a potential meaningful interpretation. By doing so, we hope we can combine both the aspects of spatial structure and aspects of people's cognition and behavior into the visibility analysis.

1.4 The Targeted Visibility Analysis: A New Script in Depthmap

As we discussed above, there are some critical locations which can influence the distribution or movement of people in architectural spaces. However, the generic visibility analysis is based on all visible locations, rather than selected critical locations. Our measures want to address the gap, by performing visibility analysis related to specific locations. Depthmap, written by Alasdair Turner at UCL is taken as the point of departure and a new script is developed using Depthmap capabilities. Here we implement two measures, targeted visual connectivity, and targeted mean step depth. Targeted visual connectivity represents the number of unique specified targets can be seen from a point. It is a local property of targeted visibility analysis. The targeted visual mean depth represents the average number of turns that need to be traversed in order to see each of a number of specified targets. It is a global property which captures the relationship between one point and the whole system of specific visual targets distributed over a layout.

Mathematically, it works in this way. First, we define a tile of point locations on the map of a layout and compute the mutual visibility between these locations. Then, we assign a unique numeric value to each specific visual target, which can be represented by either a point or an area (i.e. a bundle of adjacent points). After that, we calculate the number of unique values associated with all visible points from each occupiable location in the setting, which is the targeted visual connectivity value. One thing should be clarified. A target is treated as visible whether it is partially or fully visible. This represents no handicap. Targets can be redefined in more limited ways if some specific parts of them are more important. Finally, we calculate the number of turns that need to be traversed to get to see every pre-specified location. The average value is the targeted mean step depth value.

2. Emory Neural ICU as A Case Study

These targeted visibility measures are produced in the hope they might better predict people's behavior and to determine what the perceptual qualities of a building might be. To test it, we correlate our measures with the observational behavior in one intensive care unit, and compare the performance of it with that of generic visibility analysis. The setting, the behavioral variables and visibility variables used in the study are described below.

2.1 Setting

Figure 1

It represents variable of targeted visual connectivity, which the number of patient beds that are visible from any locations (The darker color represents the higher value). It has 10 values which range from 0-9.

The setting is the Neurological Intensive Care Unit the Emory University Hospital (FIGURE 1). It is a 20 bed facility, housed in a recently redesigned unit of the hospital. The staff of the ICU on any given weekday includes 11 registered nurses (baseline staffing level), 1 nurse manager, 3 nurse practitioners, 1 attending physician, 2-3 resident physicians, and consulting inpatient services, e.g. neurology.

2.2 Observational Data

Observational data were collected by a group of 5 observers over a period of 2 weeks. The aim of the observation was to capture aggregated patterns of distribution of people and their behaviors in the setting. Each observer recorded the location and activity of all people he/ she sees on the observation sheets while walking through the setting according to a pre-defined path. Each round takes about 10 minutes, with 15-minute interval. A total of 46 observations were made which were evenly divided among morning and afternoon shift on each workday.

The behaviors recorded here include interaction (the response is yes/no), surface-using (yes/no), computer-using (yes/ no), identity (nurse/ doctor/ nurse practitioner/ family/ patient). Later, all the data were input into ArcviewGIS 3.2 for further analysis. All clusters observational data within patient rooms were removed from the analysis, because these data can be explained by conditions of patient rather than the spatial effects. The aggregated data table (TABLE 1) show 946 counts of people presented in the setting including 320 doctors (D) and 626 nurses (RN), with almost half of them are interacting with others.

IDENTITY * INTERACT Crosstabulation

			INTERACT		
			False	True	Total
IDENTITY	D	Count	187	133	320
		% within IDENTITY	58.4%	41.6%	100.0%
		% within INTERACT	39.0%	28.5%	33.8%
	RN	Count	293	333	626
		% within IDENTITY	46.8%	53.2%	100.0%
		% within INTERACT	61.0%	71.5%	66.2%
Total		Count	480	466	946
		% within IDENTITY	50.7%	49.3%	100.0%
		% within INTERACT	100.0%	100.0%	100.0%

Table 1

The counts for presence of staff members when we aggregate all 46 observation snapshots. There are a total of 946 counts of people including 320 doctors and 626 nurses.

2.3 Visibility Variables

Nurses in the setting should pay close attention to their patients who are severely ill and immobile. We test the proposition that the critical visibility towards patient beds impacts the distribution patterns of staff members here. Thus, the targeted visual connectivity value is based on patient beds in this unit. The unit of measure is the number of unique patient beds that are visible from any given location. With the script we developed, targeted visual connectivity towards patient beds could be calculated and represented graphically. The value ranges from 0 to 9, which is the minimum and maximum number of beds could be seen simultaneously in the setting.

We use number of people per unit area as our dependent variable, which is calculated by dividing the number of people at each level of targeted visual connectivity value with corresponding number of unit tiles at that level. First, it is obvious to see the distribution of targeted visibility is not equal. Most points have a visual connectivity value less than 2. By computing the density of occupancy, rather than absolute occupancy scores per targeted visibility zone, we normalize for the uneven area of the various targeted visibility zones. Second, all points at each level of targeted visual connectivity value have constant visual information (i.e. the number of beds visible from a point). By aggregating the data according to targeted visual connectivity, we can focus on the effect of targeted visual structure.

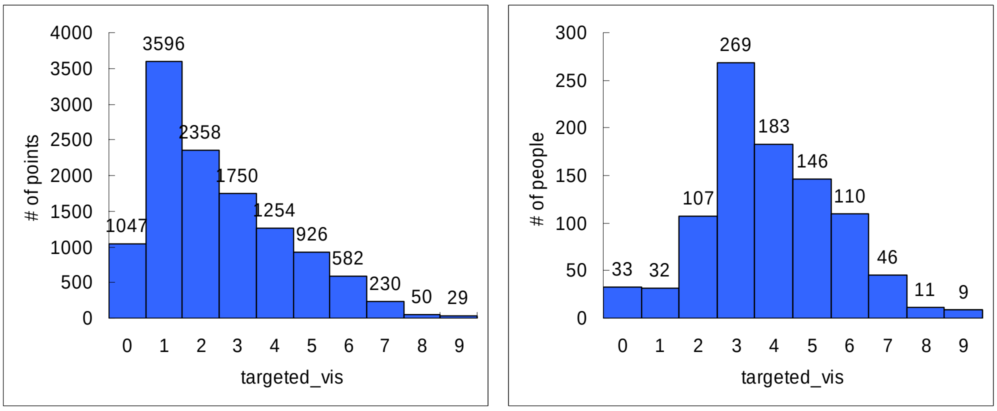

Figure 2
The left figure shows the number of points at each level of targeted visual connectivity value. The right figure shows the number of people presented at each level of targeted visual connectivity value.

We also compute generic visual connectivity, the standard output of Depthmap. It measures the number of points that are visible from a location, which roughly represents to the size of isovist. The value ranges from 85 to 4555.

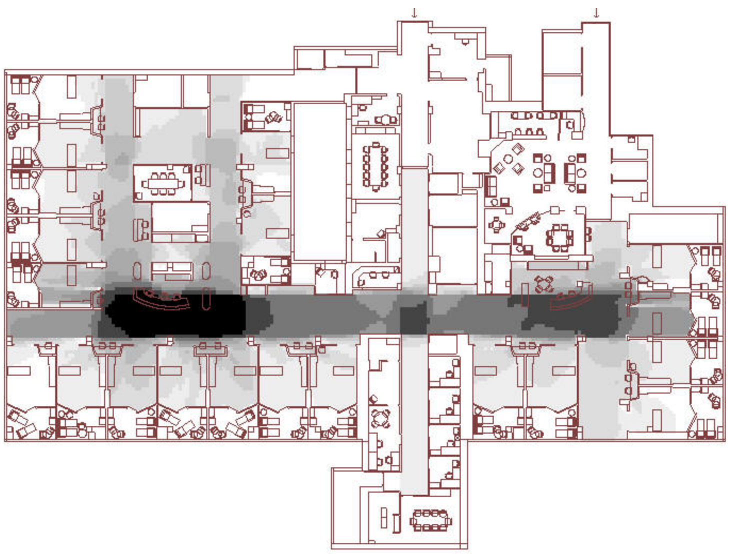

Figure 3
It represents variable of generic visual connectivity. It measures the number of points that are directly visibility from any locations (The darker color represents the higher value). The value ranges from 85 to 4555.

In order to study how generic visual connectivity impacts behavior as compared to targeted visual connectivity, and given that there are only 10 targeted connectivity values, the generic visual connectivity was divided into 10 levels with equal intervals, and recoded into an ordinal variable which ranges from 1-10. The following figures show the number of points and people at each level of recoded generic visual connectivity value.

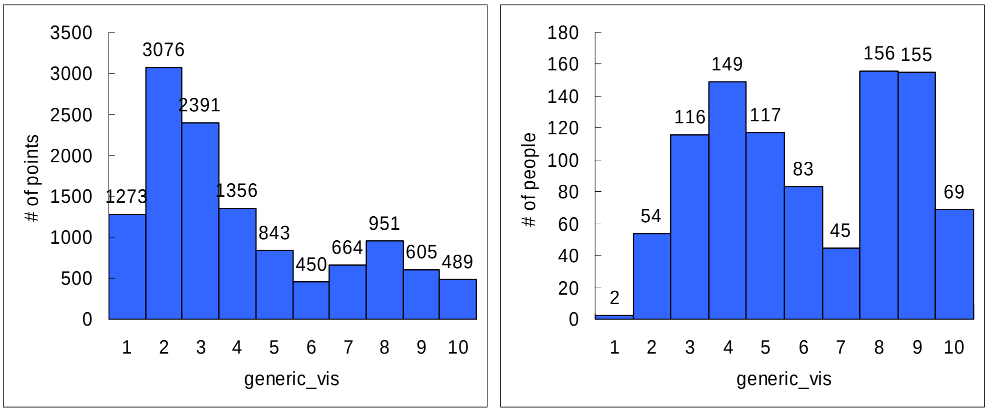

Figure 4
The left figure shows the number of points at each level of generic visual connectivity value, which is broken into 10 levels with equal intervals. The right figure shows the number of people presented at each level of generic visual connectivity value.

3. Correlational Analysis of Visibility Variables

Considering generic visibility at all points, the density (number of people per point on the visibility grid) of all staff members at specific levels of generic visual connectivity shows a very significant positive correlation with the rank of levels (Pearson's correlation coefficient r=0.786, p=0.007). Staff members are composed of nurses and doctors who have different task assignments. It is worthwhile to decompose the data into different categories: the nurses and doctors. They show different patterns of their distribution in the setting. Doctors show the same pattern of distribution with respect to levels of visibility, i.e. the density of doctors at any level of visibility is highly correlated with the rank of the level (r=0.805, p=0.005). For nurses, however, the corresponding correlation is both weaker and barely significant (r=0.634, p=0.049). We further split the data according to interacting status (interacting and not-interacting). The correlations for the interacting doctors and not-interacting doctors are significant (r=0.811, p=0.004 and r= 0.747, p=0.013 respectively). For nurse, the correlation for interacting nurses is also significant (r=0.817, p=0.004), but that for non-interacting nurses is not (r=0.359, p=0.309).

Considering targeted visibility towards patient beds at all points, the density (number of people per point on the visibility grid) of all staff members at specific levels of targeted visual connectivity shows a nearly perfect positive correlation with the targeted visual connectivity value (r=0.952, p<0.001). Doctors show a much weaker and non-significant correlation (r= 0.482, p=0.158).Nurses while show a high correlation with respect to levels of targeted visual connectivity, i.e. the density of nurses at any level of visual connectivity is highly correlated with targeted visual connectivity value (r= 0.924, p<0.001). Again, we further split the data according to interacting status. Both correlations for the interacting doctors and not-interacting doctors are not significant (r= 0.593, p=0.071 and r= 0.208, p= 0.565 respectively). However, the interacting nurses and non-interacting nurses show different patterns. The correlation for interacting nurses is strong and significant (r=0.894, p<0.001), but that for non-interacting nurses is not (r= 0.566, p=0.088).

To sum up, targeted visual connectivity is more strongly correlated with the density of all staff members compared with generic visual connectivity. It is also more strongly correlated with the density of all nurses and the density of the interacting nurses. While generic visual connectivity is more strongly correlated with the density of doctors, both interacting and not-interacting ones compared with targeted visual connectivity.

The presence of work surfaces in this setting, including central nurse stations, distributed work stations and computer stations, may also influence the distribution of staff members. Thus, it may threaten the internal validity for the behavioral impact of visual structure. To rule out this alternative explanation, we performed the previous analysis again with all staff members engaging work surface and/or computer were excluded from our record and correlational test. Our new data set has 515 counts of staff member, who are engaging neither work surface nor computer, including 199 doctors and 316 nurses.

Considering generic visibility, the correlation for all people remains strong and significant ($r=0.786$, $p=0.007$). The correlation for doctors is stronger compared with that for nurses ($r=0.820$, $p=0.004$ and $r=0.732$, $p=0.016$ respectively). The correlations for the interacting doctors and not-interacting doctors are both significant ($r=0.817$, $p=0.004$ and $r= 0.735$, $p=0.015$ respectively). The correlations for the interacting nurses and not-interacting nurses are also both significant ($r=0.753$, $p=0.012$ and $r= 0.689$, $p=0.027$ respectively).

Considering targeted visibility, the density of all staff members at specific levels of generic visual connectivity is still strongly correlated with generic visual connectivity value ($r=0.916$, $p<0.001$). The correlation for doctors is weak and not significant ($r=0.420$, $p=0.227$). The correlation for nurse remains high ($r=0.945$, $p<0.001$). However, the correlation for the interacting doctors is barely significant ($r=0.639$, $p=0.047$), and that for not-interacting doctors is not significant ($r= 0.013$, $p=0.971$). For nurse, the correlation for interacting nurses is remains high ($r=0.890$, $p<0.001$), but that for non-interacting nurses is not ($r=0.331$, $p=0.351$).

After all staff members engaging work surfaces were removed from our analysis, the correlations become slightly stronger, but the overall pattern remains almost unaffected. Targeted visual connectivity is still more strongly correlated with the density of all staff members, nurses, and interacting nurses compared with generic visual connectivity. Generic visual connectivity is still more strongly correlated with the density of doctors, both interacting and not-interacting ones compared with targeted visual connectivity.

The results indicate that nurses especially interacting nurses are more tuned to targeted visibility. And doctors are more tuned to generic visibility. In other words, proportionally more nurses can be expected in the areas with higher visibility towards patient beds. While proportionally more doctors can be expected in the locations associated with a larger view field.

4. Discussion

The explanation for the observed behavioral patterns of nurses and doctors can be linked to their different roles.

In this ICU, each nurse is normally assigned to two adjacent patients. Nurse is required to pay close observation towards their patients. At the same time, nurses need to interact with other people for all kinds of reasons, including transmission of work-related skills and knowledge, communication and socialization, reaching for help. The situation is true in this study, with more than half of observed nurses (333 of 626 counts) are interacting with others. When two nurses need to interact with each other, the preferred locations should within the overlapping isovists from all of their patients. They consciously or unconsciously negotiate a location to talk where both of them can keep their patients under close observation. One the other hand, the doctors are not anchored in any particular room, and they are required to round among all patient rooms. They tend to locate themselves where they can see a larger area, which gives them a better awareness of the surrounding environment and on-going situation.

Overall, this study leads to three important conclusions. The first is people with different roles (nurses vs. doctors) are tuned to different features of environment. The distribution of nurses in the setting is a result of deliberate efforts of individuals who position themselves towards areas that has a high visual access to patients, especially during interacting. The distribution of doctors can be explained by the preference for a position where they can maximum their awareness of the surrounding environment.

Secondly, from a methodological point of view, by drawing a distinction of generic visibility pattern and targeted visibility pattern, we can enhance the applicability of visibility analysis to studies of the behavioral impacts of spatial properties.

Finally, if the abovementioned points are true, we can draw some important design applications. Designers of healthcare settings should redirect their attentions from an exclusive focus on the functional and organizational parameters, to one that also considers the structure of critical visibility. Our suggestion is, by integrating the proper attention of the latter, we can propose design solutions to address important issues like work efficiency, transmission of work-related skills and knowledge and others.

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