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## COMPUTATIONAL DESIGN APPROACH FOR APPLYING NEURO-ARCHITECTURE PRINCIPLES IN HEALTHCARE FACILITIES

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## Abstract

Neuroscience tools' advancements have paved the way for neuroscience and architecture collaboration, spawning "Neuro-architecture." Neuro-architecture studies in various settings have been tentatively translated into design principles to improve the mood, perception, and satisfaction of healthcare facility users, as well as patient wellbeing and recovery rates. Integrating such principles into computational design methodologies should benefit users' mental health and reduce the gap between computational design and human mental needs. The research was conducted in two phases: in the first phase, typologies used in evidence-based design research (EBD) were applied in order to determine neuro-architecture design principles for the interior environment of healthcare facilities. In the second phase, the research employed space syntax analysis to evaluate the incorporation of neuro-architecture principles into healthcare facility interiors. The method visualises and evaluates spatial qualities that reflect the application of planning and navigation neuro-interior principles for the inpatient ward of a healthcare facility

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Evidence-based design, navigation, wayfinding, spatial qualities, space syntax.

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## ABSTRACT

Neuroscience tools' advancements have paved the way for neuroscience and architecture collaboration, spawning "Neuro-architecture." Neuro-architecture studies in various settings have been tentatively translated into design principles to improve the mood, perception, and satisfaction of healthcare facility users, as well as patient wellbeing and recovery rates. Integrating such principles into computational design methodologies should benefit users' mental health and reduce the gap between computational design and human mental needs. The research was conducted in two phases: in the first phase, typologies used in evidence-based design research (EBD) were applied to determine neuro-architecture design principles for the interior environment of healthcare facilities. In the second phase, the research employed space syntax analysis to evaluate the incorporation of neuro-architecture principles into healthcare facility interiors. The method visualises and evaluates spatial qualities that reflect the application of planning and navigation neuro-interior principles for the inpatient ward of a healthcare facility.

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## ملخص

مهتد التطورات التي حققتها أدوات علم الأعصاب الطريق للتكامل بين علم الأعصاب والعمارة، مما أدى إلى ظهور ما يسمى بـ"العمارة العصبية". وقد اهتم هذا البحث بترجمة دراسات العمارة العصبية في سياقات مختلفة مبدئيًا إلى مبادئ تصميم لتحسين الحالة المزاجية والإدراك والرضا لمستخدمي مرافق الرعاية الصحية، فضلاً عن معدلات رفاة المريض والتعافي. ومن الواضح أن دمج هذه المبادئ في منهجيات التصميم الحوسبي ذو فائدة بالنسبة للصحة العقلية للمستخدمين وتقليل الفجوة بين التصميم الحوسبي والاحتياجات العقلية البشرية. تم إجراء البحث على مرحلتين: في المرحلة الأولى، تم تطبيق الأنماط المستخدمة في أبحاث التصميم القائمة على الأدلة (EBD) من أجل تحديد مبادئ تصميم العمارة العصبية للبيئة الداخلية لمرافق الرعاية الصحية. وفي المرحلة الثانية، استخدم البحث علم تحليل بنية الفراغات لتقييم دمج مبادئ العمارة العصبية في التصميمات الداخلية لمنشآت الرعاية الصحية. تقوم المنهجية المتبعة بتصوير وتقييم الصفات المكانية التي تعكس تطبيق مبادئ التخطيط والملاحة الداخلية العصبية لمرضى الداخلين في منشأة الرعاية الصحية.

**الكلمات المفتاحية:** التصميم القائم على الأدلة، الملاحة الفراغية، علم إيجاد الطريق الفراغي، السمات الفراغية، علم بنية الفراغات.

## 1. INTRODUCTION

Understanding how spaces influence people has long been a priority for architects and environmental psychologists. Their conclusions, however, were founded on empirical research. Using evidence-based design, they studied how people act differently in diverse contexts. However, because to technical constraints at the time, such studies were unable to detect brain responses in the same way that they are now. As a result, they are unable to deal with the full intricacy of the relationship between neurology and architecture. Nonetheless, the capacity to consciously process information is less than 1 percent of the ability to process information in an unconscious manner (Nani and Cavanna, 2012). As a result, the factual observations from external observers or the user’s conscious opinions are only the result of the response to the stimulus, not the actual response.

It has been consistently proven that hospital architecture has an influence on patient satisfaction with treatment, emotional condition, and rate of recovery (Ulrich et al., 2008). Results from studies conducted in selected medical conditions have been tentatively translated into design principles that are applicable to health-care environments and the application of these principles is recommended to enhance recovery (Dan, 2016). Measurements of spatial features, visual parameters, and visibility analysis study may provide a novel and adaptable paradigm for the quantitative examination of the application of neuro-architecture interior design principles in healthcare facilities. As such, this study intends to investigate space syntax analysis as a computational methodology for evaluating the interior spaces of healthcare facilities through the analysis and measurement of several visual and spatial qualities that can ensure the use of neuro-interior design principles.

## 2. NEURO-ARCHITECTURE: THE EFFECTS OF SPACE ON THE BRAIN

The relationship between the human brain and the built environment has been studied from both theoretical and methodological perspectives. The relationship between neuroscience and architecture was divided into three categories by (Arbib, 2013). Individual reactions to the built environment are the subject of this research.

Neuroscience technologies such as psychophysiological measurements and brain imaging methods paved the way for collaboration between neuroscience and architecture. Because the study topic is interdisciplinary, the collaboration utilizes several techniques that include environmental, behavioral, and neurological components using digital technology. As seen in Figure1, below are the several approaches used in neuroscience and architecture research that are described in literature.

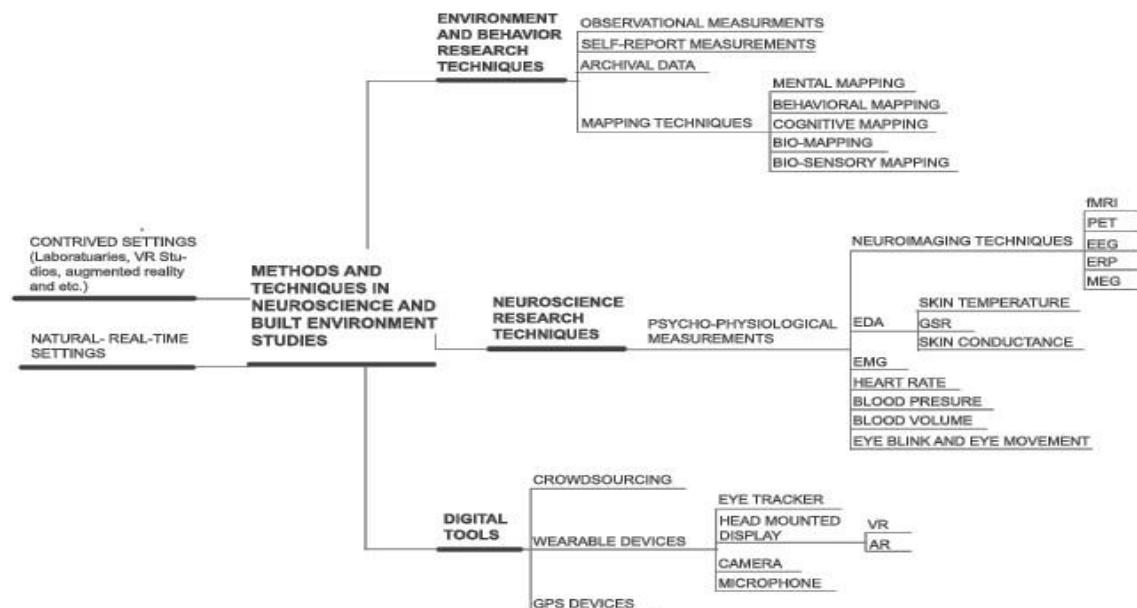


Fig.1: Research methods for the built environment and neuroscience investigations (Karakas and Yildiz, 2020)

### 3. NEURO-ARCHITECTURE DESIGN PRINCIPLES FOR HEALTHCARE FACILITIES

The ideal approach to developing a technique for applying neuroscience to interior design is to first comprehend and investigate the findings of neuroscience in connection to interior space, as well as the case studies in which these discoveries were applied. The design process begins with the identification of the many stimuli that must be elicited inside an interior space. Additionally, it is critical to comprehend the various interior spaces and their main aspects, as well as to use neuro-design concepts aimed at eliciting inspiration or a sense of enlightenment (Refer to Figure 2).

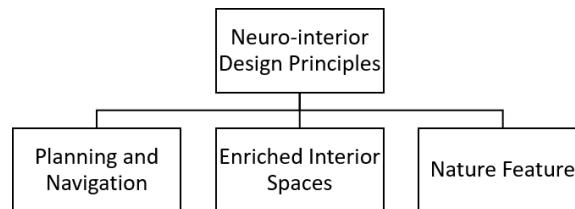


Fig.2: Neuro-Design Principles (Ibrahim, 2019)

To begin comprehending the relationship between neuroscience and interior space, we may look at our fundamental actions, which include the use of our five senses to perceive our surroundings. There is no doubt that perception involves spatial properties such as color, light, texture, smell, and sound, as well as our navigation through space, where the human brain registers sensations through sight, sound, and touch, and interior design elements such as form, color, materials, natural light, and nature influence the human psyche. Neuroscience explores the influence of our physical surroundings on our cognition, problem-solving abilities, and emotions. Understanding these concepts can help interior designers build spaces that promote spatial orientation while also reinforcing cognitive abilities and mitigating negative emotional and motivational effects. There are several design concepts for interior spaces that are influenced by neuroscience. Classifying these concepts clarifies the neuro interior design process and enables the designer to adjust them for diverse spaces (Refer to Figure 3).



Fig.3: Healthcare facilities neuro-interior design principles classification

Space visual/ locomotive permeability is confirmed to have effects on the brain with activating structures underlying perceived visual motion, so closed rooms elicit exit decisions and activated the anterior midcingulate cortex (aMCC) in contrast with open rooms (Vartanian et al., 2015). Poor wayfinding may induce anxiety, whereas excellent wayfinding design can reduce stress. (İlker Erkan, 2018; Morag et al., 2016). According to these findings unobstructed lines of sight linking entry spaces and other critical, central spaces such as atria to vertical circulation systems such as staircases in addition to frequent and consistent sight lines to

elements such as exterior vistas, atria, or visually significant architectural features should be taken into consideration when planning. These also could positively affect wayfinding behavior according to (Dalton et al., 2015). When planning multilevel-facility, minimization of the disparity in multi floor plans is recommended that's because users will think that each floor is identical to the preceding one. Deviating too far from this will lead to needless confusion. (Hölscher et al., 2006; Dalton et al., 2015)

According to Ulrich's theory of supportive design, perceived control in the design of a healthcare facility can be achieved by assuring accessibility to all spaces, corridors, toilets, and services. (Harris et al., 2002; Andrade et al., 2017)

#### 4. COMPUTATIONAL APPROACH FOR INTEGRATING NEURO-ARCHITECTURE PRINCIPLES IN THE INTERIOR ENVIRONMENT OF HEALTHCARE FACILITIES

The research emphasizes on the planning and navigation neuro-architecture principles and introduces a space syntax analysis computational approach for the evaluation of the spatial qualities of healthcare facilities. The approach focuses primarily on the spatial configuration of the healthcare facility's floor plans and the quantification of spatial qualities in order to apply neuro-design principles targeting the wayfinding behavior of visitors to inpatient wards, in addition to the visual connectivity between nurses' stations and inpatients' room entrances and between nurses' stations and each other. Because a good wayfinding experience reduces stress and anxiety, visual connection to inpatient rooms is expected to positively encourage nurses to provide more care for patients, and the inter-visibility between the nurses' stations and each other supports the social interaction, satisfaction, and performance of nurses, thereby enhancing the quality of the medical care they provide. Depthmap X is used to analyze the main benchmarks involved in measuring spatial qualities, such as visual connectivity, integration and 2D isovists.

##### 4.1. Space Syntax Analysis Methodology

In the areas of neuroscience, cognitive science, and space syntax research there is a growing body of evidence that provides a foundation for design, especially in the case of wayfinding and navigation in complex buildings like the case in healthcare facilities. Although these studies were not applied with neuroscience tools and brain neural activity was not recorded, these findings were supported through empirical experiments and observations not through questionnaires. So, these studies could be considered dependable considering that poor wayfinding may induce anxiety, whereas excellent wayfinding design can reduce stress. (İlker Erkan, 2018; Morag et al., 2016) (Refer to Figure 4).

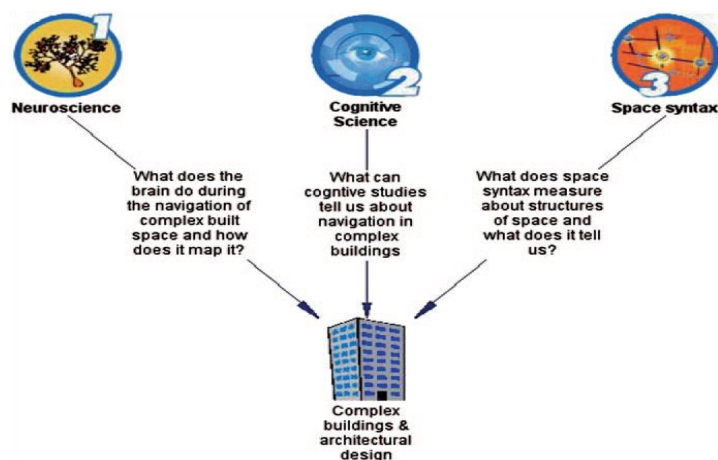


Fig.4: The relative contributions of neuroscience, cognitive science, and space syntax analysis to the design of complex buildings (Dalton et al., 2015)

Space Syntax theory and methodologies have improved during the previous four decades. (Hillier and Hanson, 1984; Hillier et al., 1978) The development of the theory has led to mathematical and technical techniques, as well as the creation of several

computer software applications. According to Baskaya et al. (2004), space syntax and wayfinding systems are influential environmental elements for indoor wayfinding. Since the late 1990s, Space Syntax has been used extensively in the analysis of healthcare facilities. As a result of this shift in emphasis and the number of papers published since then, Space Syntax is now important to healthcare researchers.

Based on its theoretical tenets, Space Syntax offers a variety of computer programs for analyzing plan drawings. Since the value of a space is determined by its relationship to all other spaces, any change in the number of spaces in the design (known as the spatial system) or in the connection pattern anywhere (a door added or removed, a corridor blocked off, etc.) will alter the value of that place. In most cases, space numerical measurements are statistically compared to a performance indicator, and conclusions are drawn based on the significance of the comparison (Haq and Luo, 2012).

Because Space Syntax may be modelled on a suggested floor plan, it has the potential to be an effective testing tool prior to detailed design or construction. In this manner, evidence may be immediately used and tested during the phase of preliminary design.

#### 4.1.1. VGA

VGA is frequently used to evaluate connection and layout integration. (Chau et al., 2018) In VGA, a grid of points is superimposed on the graph's construction design. Then, each point is connected to every other point it can perceive. VGA is utilized in this study for both connection and visual integration (Geng et al., 2020).

Visibility graph analysis helps in computationally visualizing the visual connectivity of the public spaces of a complex floor plan. This analysis helps in identifying threshold points and identification of corridors of longest line of sight which work as main routes in the floor plan. This helps in allocation of manifest cues at the threshold position and prioritizing the primary against the secondary route and altering the spatial geometry in every decision point according to this approach. Once a primary path has been identified, a new geometric design should be applied to it (Kondyli et al., 2017).

#### 4.1.2. 2D Isovist Analysis

There are several ways to depict isovist, and we claim that the discrepancies between the approaches may impact the isovist's interpretation. The technique of visualization will be determined by the representation of isovist. Visualization plays a significant part in the study since it may provide insight into the efficacy and efficiency of a system, as well as enabling the rapid identification of intriguing characteristics and trends (Wijk, 2005). Isovist may be represented as a closed polygon as in Figure 5 containing all sets of observable points from a single vantage point (Benedikt, 1979).

#### 4.1.3. Spatial Connectivity

In Space Syntax, the number of direct linkages to other spaces is referred to as connectivity. (Haq, 2003). The integration value is derived by a mathematical computation that considers both the number of corridors to which one is linked and the step depth of each of those corridor connections. A corridor with great integration is, on average, closely coupled to all other corridors in a given configuration. In comparison, a corridor that is isolated from all other corridors on an average basis is termed segregated (Haq and Luo, 2012).

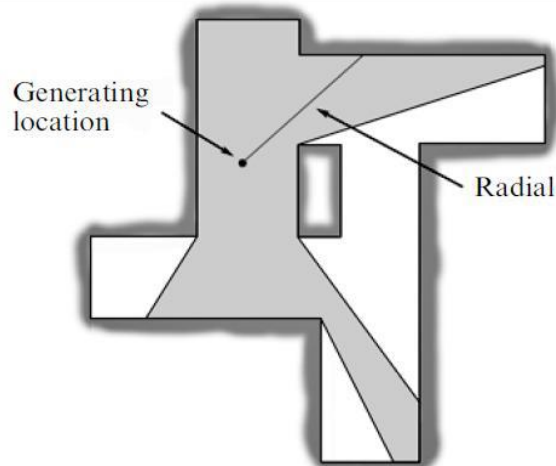


Fig.5: Polygonal depiction of isovist and the inability to visualise the influence of distance. (Turner et al., 2001)

Haq and Luo (2012) concluded the fact that corridor utilization by explorers is proportional to their integration-n values. Moreover, when undecided about where to travel, a bigger share of visitors chooses destinations with higher integration values. Another lesson learned is that more people tend to congregate in more integrated locations.

Yi and Bozovic-Stamenovic (2009) found significant correlations between Syntax scores and both space exploration and navigational use. Consequently, they reinforced the relevance of integration values in wayfinding and exploration, indicating that these aspects are consistent independent of the design ideas of individual buildings. (Haq, 2003) investigated a variety of Syntax variables and approaches for characterizing plans from the perspective of Space Syntax. Integration-3 revealed to be the most significant predictor of hospital building wayfinding.

Haq et al. (2005) highlighted prior findings about the predictive value of axial integration-3 for hospital visitor navigation and spatial cognition. In conclusion, an integration study of a hospital's design accurately predicts which corridors visitors are likely to stroll through and remember.

Previous research confirms that Syntax factors have a crucial influence in predicting which hospital corridors would be more commonly utilised by visitors exploring and navigating. Integrated corridors are also more likely to be "mapped" in cognitive knowledge and may thus play a larger role in navigation.

## 4.2. Case Study

Four new hospitals in Cairo, Egypt, have been selected for analysis. Refer to Table 1. It was intended to rely on the floor plans' analysis and simulation rather than post-occupancy observations, so that the approaches offered may aid in the preliminary design process. In addition, the study's findings may be of use to decision-makers at the four institutions. VGA was made for the floor plans of the inpatient wards of the four hospitals. In order to compare their spatial configurations 2 of each nurse stations were chosen to share the same typology. These graphs have been shown to have a correlation with ease of access and wayfinding, and a positive wayfinding experience has been shown to positively affect the mind of the navigator and reduce stress and anxiety, particularly in stressful environments such as hospitals.

In addition, a 2d Isovist analysis is performed on the inpatient wards of the four hospitals in order to examine the social-psychological and environmental support anticipated from the current spatial configuration of the inpatient ward and the inter-



visibility between nurse stations and inpatient room entrances. Monitoring the entrances to the inpatient rooms provides patients and their families with a sense of safety and security, which reduces stress. Also, empirical evidence demonstrates that a sense of control and privacy for patients and their families reduces stress levels and consequently improves mental and physical health.

The analysis also considers how the patient's room is viewed from the nurse's station to ensure privacy. On the same inpatient ward, the visibility between nurse stations and each other is investigated. Visibility between nurse stations facilitates social interaction and positively impacts performance. The purpose of the study for the four hospitals is to utilize a computational approach for analyzing and evaluating spatial and visual configurations that support the neuro-architecture principles associated with wayfinding behavior and social and psychological support of healthcare facility users.

**Table 1. Research Settings**

Abbr.	Hospital Name	Inpatient Ward Typology
H1	Ahl Masr Hospital	Racetrack (Linear Double Corridor)
H2	Ain Shams for Pediatric Surgery Hospital	Single Corridor
H3	New Baheyya Hospital	Single Corridor
H4	Magdy Yacoub New Global Heart Center	Racetrack (Linear Double Corridor)

#### 4.2.1. Visual Integration Analysis

The visual integration analysis is made on the inpatient ward of H1 of the first-floor plan by Depthmap X software. The ward consists of 17 inpatient room and 3 nurse stations. The typology of the ward is linear double corridor. The average visual integration of the nurse stations concluded from the graph is equal to 7.13. The graph depicts the presence of nurse stations in areas with the greatest visual integration. This is anticipated to be beneficial for both ward navigation and care distribution among inpatients (Refer to Figure 6).

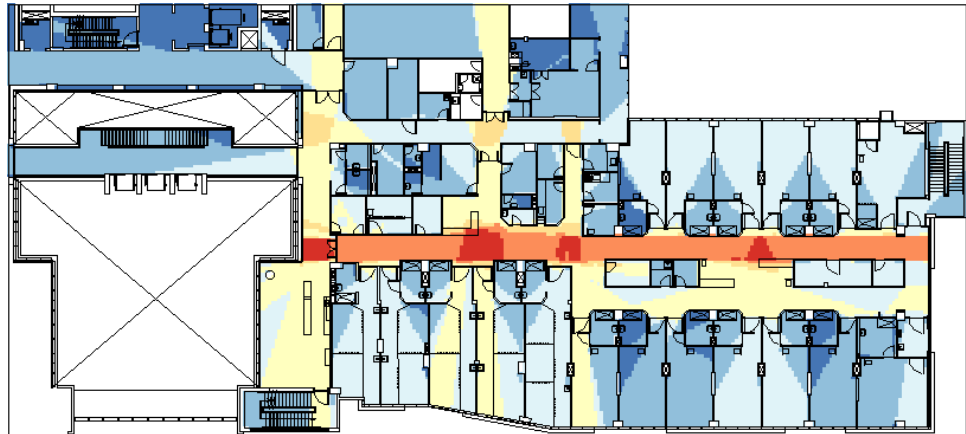


Fig.6: Visual Integration of Inpatient Ward of H1 by Depthmap

For H2, the inpatient ward consists of 13 inpatient rooms and 2 nurse stations. The typology of the ward is single corridor typology. The average visual integration of the nurse stations concluded from the graph is equal to 6.26. Even though H2 and H3 inpatient wards share the same typology, the locations of their nurse stations differ. The placement of one of the 2 nurse stations in H2 are in marginally lower visual integration zones (Refer to Figure 7).

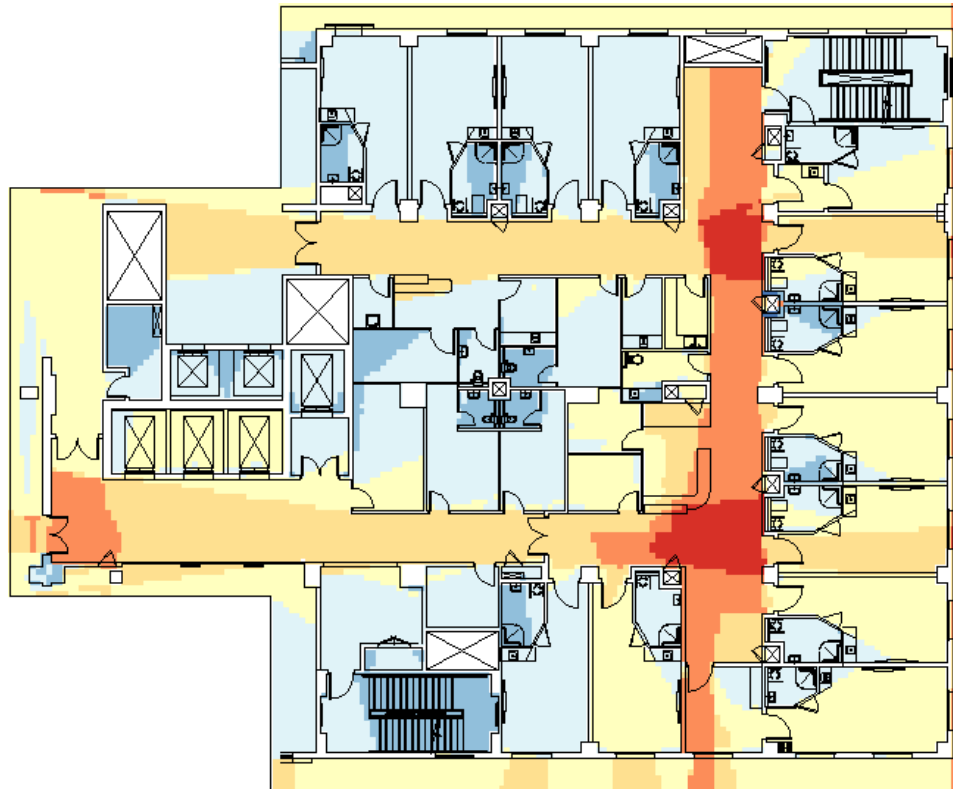


Fig. 7. Visual Integration of Inpatient Ward of H2 by Depthmap

The visual integration analysis was also made on the inpatient ward of H3 of the second-floor plan. The ward consists of 14 inpatient room and 2 nurse stations. The typology of the ward is single corridor typology. The average visual integration of the nurse stations concluded from the graph is equal to 6.57. Knowing that the highest visual integration for this inpatient ward is 10.60, the graph indicates that nurse stations are not located in the most integrated areas of the floor plan (Refer to Figure 8).

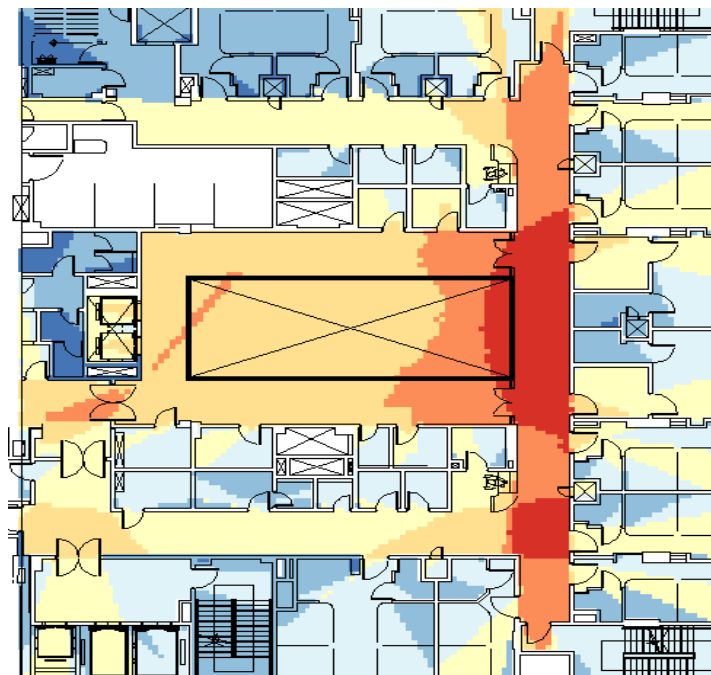


Fig.8: Visual Integration of Inpatient Ward of H3 by Depthmap

The inpatient ward of H4 consists of 28 inpatient room in addition to 3 isolation rooms and 4 nurse stations. The typology of the ward is double corridor

typology. The average visual integration of the nurse stations concluded from the graph is equal to 6.34. H4 inpatient ward shares the same typology with that of H1 which is linear double corridor but for almost double the number of inpatients rooms. The visual integration analysis result shows the allocation of the adults' isolation inpatient room in a low visually integrated area. The main nurse station is located near high visually integrated areas, which is not the case for the last 2 nurse stations. This might indicate the difficulty of wayfinding inside the ward (Refer to Figure 9).

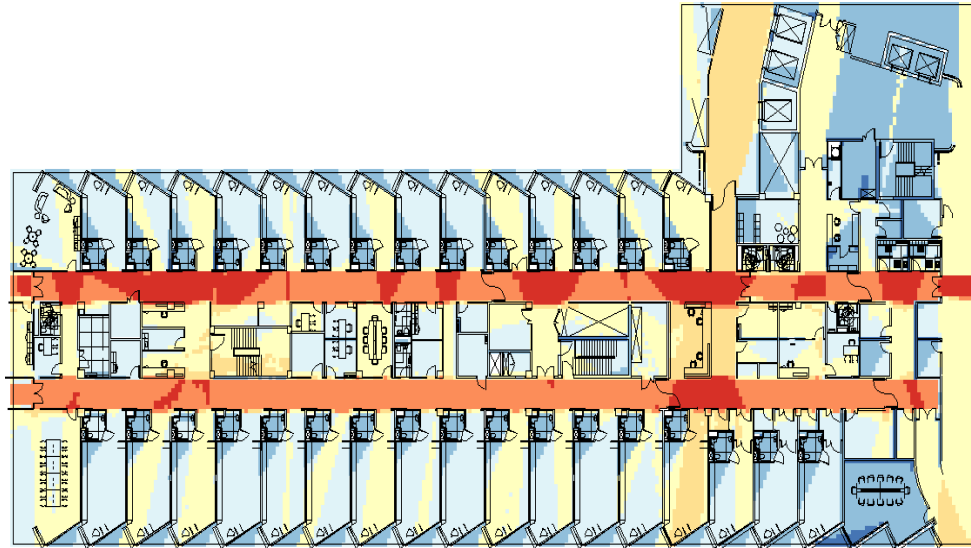


Fig.9: Visual Integration of Inpatient Ward of H4 by Depthmap

#### 4.2.2. Isovist Analysis

For H1, inpatient beds are not visible from nurse stations, resulting in increased patient privacy but a diminished sense of security. Four out of the seventeen inpatient rooms are not visible from the stable nurse stations. The patients and their families can anticipate receiving less care and feeling less secure in these rooms. The graph also illustrates the inter-visibility among three nurse stations (Refer to Figure 10).

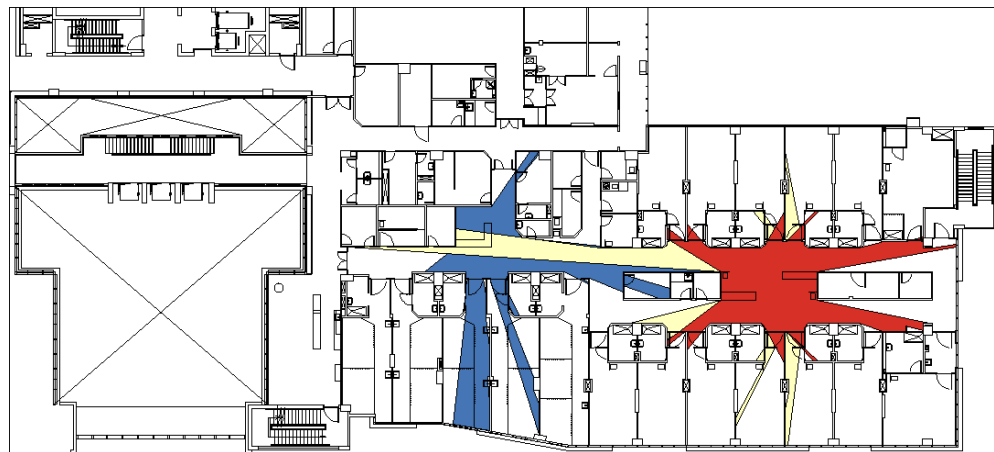


Fig.10: Isovist graph analysis for H1 Inpatient Ward by Depthmap

Regarding H2, the isovist analysis of the inpatient ward's nurse stations shows no mutual visibility between nurse stations and that 3 of the 13 rooms entrances are not directly visible from the stations. Also, the graph shows that for some rooms, patients' privacy may be affected by the location of the nurse station near the ward entrance from the visitor elevators' lobby (Refer to Figure 11).

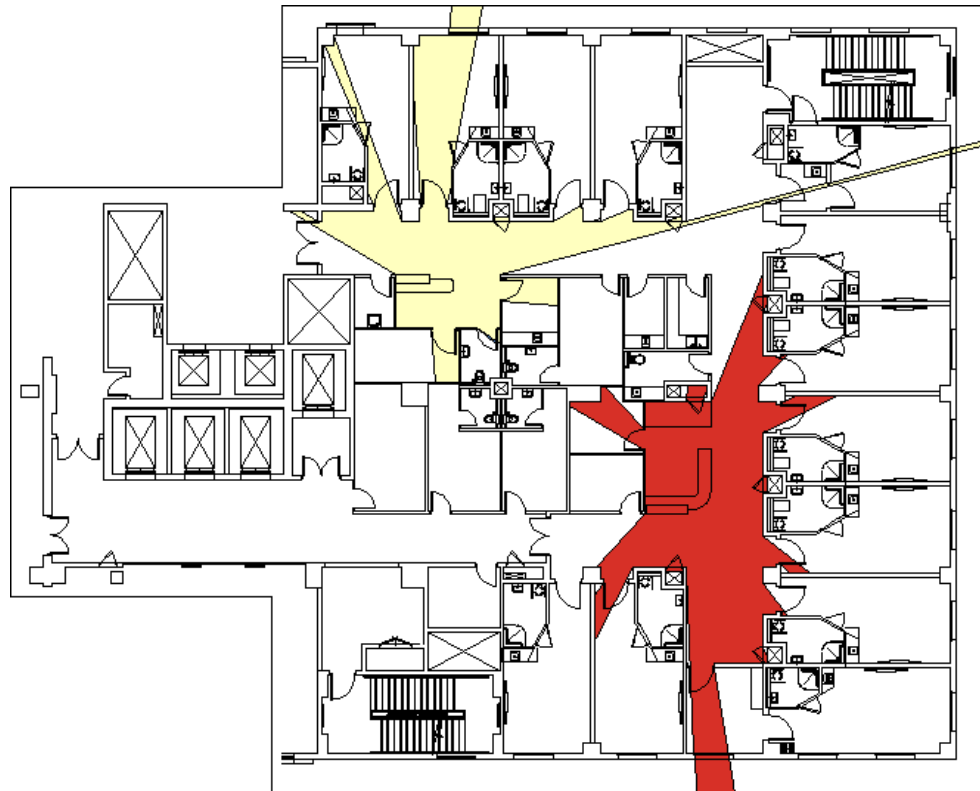


Fig.11: Isovist graph analysis for H2 Inpatient Ward by Depthmap

Four of the fourteen inpatient rooms of the inpatient ward of H3 are excluded from the view field of stable nurse stations (Refer to Figure 12).

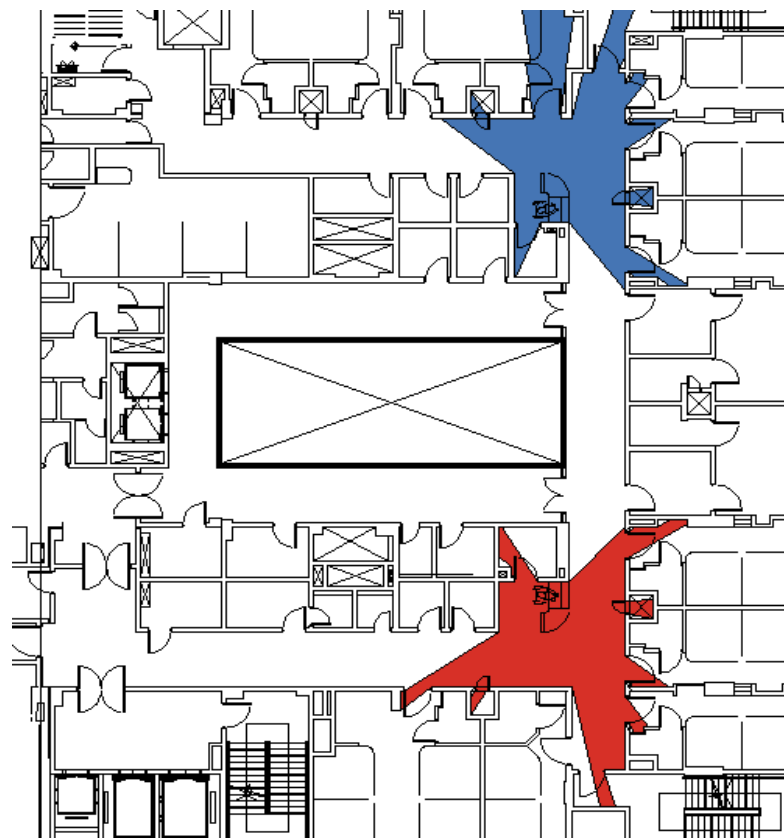


Fig.12: Isovist graph analysis for H3 Inpatient Ward by Depthmap

The lack of mutual visibility between the four nurse stations of the inpatient

ward of H4 is revealed by the isovist analysis of the nurse station locations, which would have a negative impact on nurse interaction and performance. Furthermore, none of the nurse stations monitor sixteen of the thirty-one rooms. This could impact the patients' and their families' sense of security. In addition, the isovist analysis reveals that certain rooms are completely observable from the nurse station, which would compromise the patients' and their families' sense of control and privacy (Refer to Figure 13).

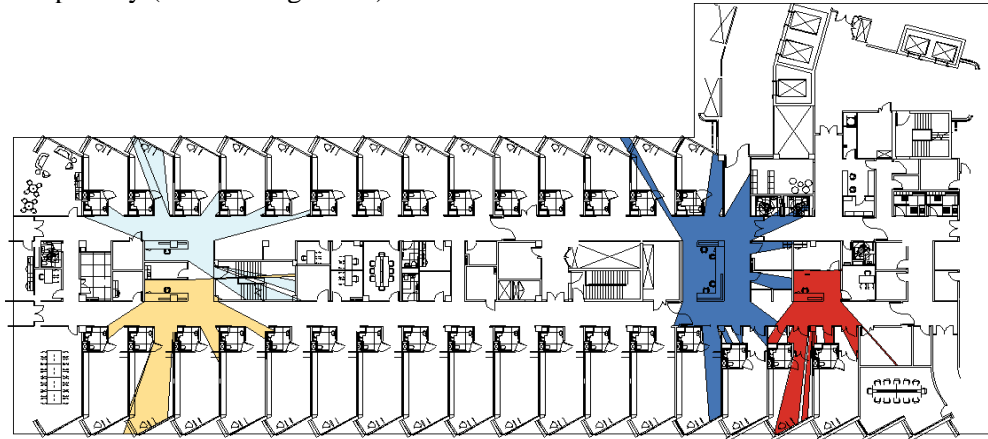


Fig.13: Isovist graph analysis for H4 Inpatient Ward by Depthmap

#### 4.2.3. Results

Although H2 and H3 share the same single corridor layout and nearly the same number of inpatient rooms, the H3 inpatient ward's nurse stations have a slightly higher average visual integration of 6.57 than that of H2. This may indicate that positioning nurse stations at threshold locations like the case in H3 might be better for the visitors to find their way easier.

The difference in the visibility analysis was because of the distribution of the nurse stations and inpatients rooms entrances. This distribution of the nurse stations of H2 ensured slightly better visibility to more inpatient rooms entrances than that in H3. Higher visibility to inpatient rooms entrances from nurse stations predicts more visits to the rooms according to empirical psychological studies and observations. Also monitoring inpatient rooms entrances increases sense of security and safety for patients and their families according to studies mentioned. Both nurse stations in the 2 hospitals have no inter-visibility between each other. This is not recommended for the importance of the social support of the nurses which might affect the performance and care given to patients.

Among to the 4 hospitals, H1's inpatient ward nurse station has the highest visual integration (7.13). Even though H1 and H4 inpatient wards share the same Racetrack (double corridor) typology, H4 inpatient ward nurse stations were not found to have a high visual integration value to inpatient rooms' entrances in relative to the rest of the nurse stations of the four hospitals even though studies confirm the advantage of the double corridor over that of single corridor. This may be because of the large number of inpatient rooms in H4 inpatient ward (31 inpatient rooms in comparison to 17,13 and 14 inpatient rooms for H1, H2, H3). The isovist analysis of the inpatient ward of H4 shows bad coverage of the inpatients rooms entrances (16 of 31 inpatient rooms aren't visible from the stable location of nurse stations of the ward compared to 4 out of 17, 3 out of 13 and 4 out of 14 for H1, H2 and H3 respectively) and shows no mutual visibility between 4 the nurse stations. Also, the isovist analysis shows that some of the inpatient rooms are almost completely visible from the nurse station which might affect privacy and sense of control for patients and their families.

## 5. CONCLUSIONS AND DISCUSSION

This study adhered to the EBD research typologies and proposed heuristics to facilitate the application of neuro-architecture principles in healthcare facilities. This study also presented a space syntax analysis method for computationally integrating neuro-quantifiable architecture's design principles into the interior environments of healthcare facilities. This approach was introduced to visualize and evaluate the visibility and spatial connectivity of the plan layout of healthcare facilities to describe and quantify certain spatial qualities that reflect the application of the planning and navigation neuro-interior principles for the healthcare facility.

Four hospitals with different typologies of inpatient wards were chosen to apply the introduced method for visualizing and evaluating the spatial qualities of their inpatient ward's nurse station. Using Space Syntax analysis, the visual integration of the inpatient ward nurse stations and their accessibility from the visitors' elevator lobbies, as well as the distribution of the nurse stations in the ward in relation to the inpatient rooms, were analyzed. The visual integration reflects the ease of wayfinding for visitors, which has a positive effect on the visitor's brain and psychological state and reduces stress. The visibility of the inpatient room entrances, the good distribution of nurse stations within the ward, and the inter-visibility of nurse stations within the same ward all contribute to the social interaction and performance of the nurses, and thus to the quality of medical care provided to the patients. The computational method is supposed to facilitate the practical application of the neuro-architecture design principles in healthcare facilities, which have been demonstrated to positively impact the facility users' mental state, performance, and recovery rate.

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