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PRINCIPLES OF CIRCULATION AND MOVEMENT CONFIGURATIONS IN HOSPITAL DESIGN.

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ABSTRACT

Circulation paths can be defined as invisible threads linking internal and external spaces within a building relative to where a person is and the intended final destination. Various studies exist in the need to further understand the relationship between circulation and way-finding, particularly in hospital and healthcare buildings. In this study, a practical approach to hospital circulation design is presented to combine the principles of circulation as a design tool for layout configurations in the design of hospitals. This paper presents Circulation Elements as layers of flow that outline the movement paths within buildings. The study reviewed already established fundamental elements for circulation studies that are notable in architectural philosophies as major components for the way-finding process as it affects circulation in buildings. It further reviewed existing circulation systems to identify the potential patterns of circulation used in modern-day hospital buildings. These circulation principles were finally adopted in the conceptual design of a typical hospital building to justify its applicability. Analysis of the designed hospital circulation system is evaluated using VGA (visibility graph analysis) to identify the significance of carriage pathway sizes in improving visibility fields for indoor way-finding processes. The VGA analysis identified the ease of wayfinding and movement as dependent on the size of circulation spaces. This VGA method of analysis can be adopted by architects and designers for preliminary analysis of carriageways relative to circulation configuration during the design process to ensure improvement of circulation efficiency and way-finding.

Keywords: *Circulation configuration, Flow patterns, Hospital design, Principles of circulation, Visibility graph analysis*.

INTRODUCTION

Circulation may be defined as the flow of people through and within a building and its environment. In architecture, it is referred to as ways people flow and interrelate within buildings (Abdelkhalek *et al.*, 2023). Investigating Circulation Spaces on Users Experience in Retail Buildings. MSA Engineering Journal.. According to natural principles and behavior, people are known to identify their routes through spaces using choice and ease (Tong *et al.*, 2022). The study classifies typical human behavior in spaces as determined through the form and layouts of buildings (Ching, 2015). The paths taken by human movements in buildings are essentially perceived as major elements that connect the different spaces. Normal occurrence of circulation observed in architecture is therefore seen as a combination of the human natural tendency to move in one particular direction or the other. Hence, the symbiotic relationship between buildings and people that move within them creates the active flow that we refer to as *'circulation'*. Therefore, the principle that is often adopted in design to direct movement patterns in architecture is central in the definition of way-finding processes, navigation, and orientation.

Studies of circulation efficiencies in hospital designs identified circulation as significant in defining the efficiency of services. It is understood that the configuration of spaces in buildings influences human flow patterns, which actively influences the behaviors of users as they move through building space as well as impacts significantly on the level of their decisions within the building spaces (Hillier, 1996). The study also identified that the quality of patient care, health, and well-being is significantly connected to the observed physical qualities of a hospital environment (Gesler, 2004). Thus by mere action of improving human flow systems and circulation in hospitals using efficient pathways, the staff productivity and job performance can be improved, while at the same time enhancing safety, privacy rate of recovery of patients, as well as reduction in the risk of cross-infections (Nazarian, *et al.*, 2011).

The process of way-finding recognizes pathways as routes to locations. The mental process of way-finding suggests that every human (and even animals) utilizes cognitive maps in way-finding, as they are used to obtain information, recall stored information, and code/decode information regarding the locations and characters of features in any given environment (Tolman, 1948). The concept of cognitive wayfinding can be described as a process that identifies maps as recorded in the head and examined through the mind's eyes as significantly similar to graphical maps as they were observed by the eye itself (Kuipers, 1982; Kuipers, 1983).

A review of human cognition standards as identified in research reveals that the configuration of any location possesses substantial cognitive significance (Hillier, 1996). Subsequently, the spatial arrangement of every designed human environment impacts greatly the precision of the cognitive depictions of real-time spatial information and resources (Kim, 2001), (Appleyard, 1970), (O'Neill, 1991). Additionally, the network structures identified in the daily spatial activities develop into critical rudiments of the appearance of spatial environments as they are registered (Ahmadpoor, 2019; Golledge, 1997). Studies suggest that images of spatial environments are attainable if configured as structures of high continuity using distinctive and related parts. Patterns of circulation in buildings on the other hand determine the fundamental systems for the indoor way-finding process. Thus, to understand the

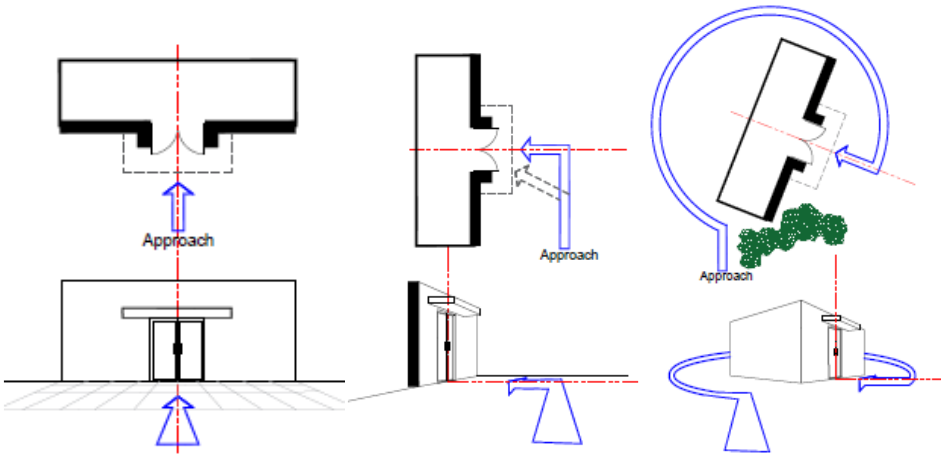
concepts of way-finding within buildings better, circulation concepts must first be understood. A clearer definition of Circulation in buildings identifies its occurrence in layers. Each layer on its own represents an important sequence in the configuration of a way-finding process. Elements that make up these layers of circulation are identified as:

- The Approach
- The Entrance
- Path Configuration
- Path and Space Connectivity
- Configuration of the Circulation Space

The Approach Layer

The first layer of circulation is the building approach. This layer considers three major entrance options as shown in Figure 1, which are:

a. The Frontal approach system
b. The Oblique approach system
c. The Spiral approach system



(a) (b) (c)

Figure 1: Illustration of the three (3) options of approaches, which represents the first layers of circulation, (Source: Ching, 2007)

The Entrance

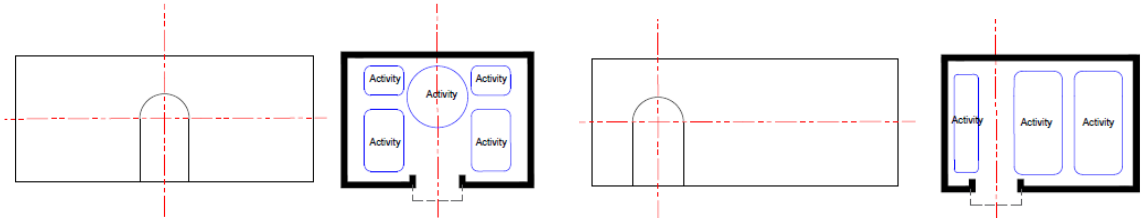
Entrance into a building, or a defined field of space, involves the act of penetration of a vertical plane, which distinguishes one space from another (Ching, 2007). Entrance into a space or a building indicates transition. Conventionally, entrance systems are created with the use of openings done within a plane. Entrances may be made to project or recess into a plane. When it is projected, entrances announce passage before penetrating the opening. However, when it is recessed, it absorbs the exterior area into the building's internal space. The options for entrances as shown in Figure 2, include:

- Centered along a plane

- Offset from the axis of entry

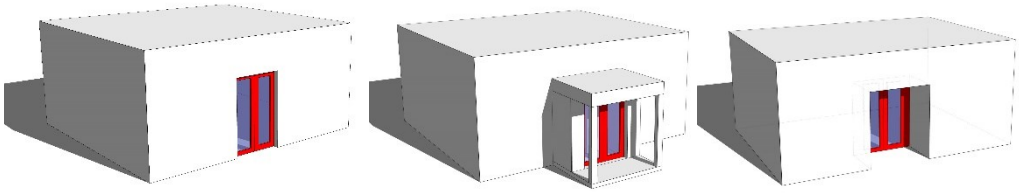
And their features (figure 3) may be:

- Flushed
- Projected
- Recessed.



(a) (b)

Figure 2: Illustration of Entrance options which represents the second layer of circulation



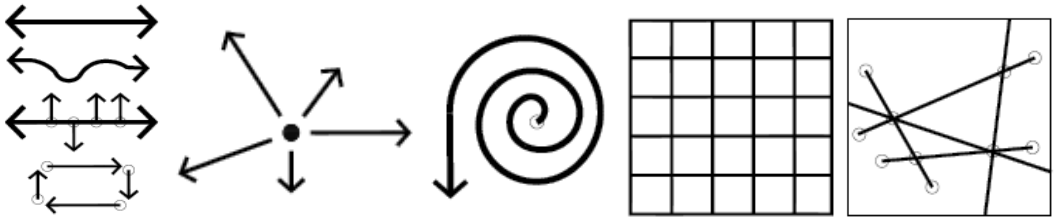
(a) (b) (c)

Figure 3: The three entrance types, (a,) Flushed, (b,) Projected, (c,) Recessed

Layer of Configuration of Paths

Primarily, all paths originate from a starting point, just as movements on all paths are linear and transverse through sequences of other spaces to a given destination. Conversely, paths can be in segmented or curvilinear form, they can also be intersected or branch outwards to other paths, as well as made to form a loop. The configuration of paths generally reinforces spatial organization by way of repeating its pattern. By so doing, the human mind cognitively maps out the total configuration of the paths within a building as a means of understanding its spatial layout (Ching, 2007). The different types of configurations include;

- Linear, Curvilinear, Radial or Spiral,
- Gridded or Networked,
- Segmented, Intersected or Looped,
- Composite



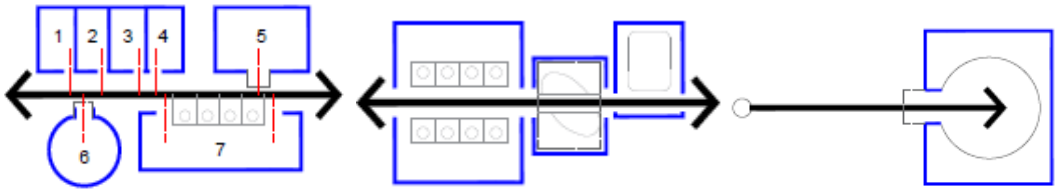
(a) (b) (c) (d) (e)

Figure 4: Types of pathway configurations; (a) Linear Configuration, (b) Radial Configuration, (c) Spiral Configuration, (d) Grid Configuration, (e) Networked Configuration.

Layer of Path to Space Connectivity

Naturally, paths relate directly to the spaces they connect to. The following distinctive modes are means paths related to spaces:

- Passing by designed spaces (flexible configurations)
- Passing through designed spaces (with potential for flow with points of rest in the space)
- Terminating in a space (established by the location of the space).



(a) (b) (c)

Figure 5: Types of path-space connectivity; (a) Pass by spaces, (b) Pass through spaces, (c) Terminate in spaces, (Ching, 2007).

Layer of Configuration/Form of the Circulation Space

The final layer of circulation is the form a circulation space takes. A typical example is the corridor or lobby leading to other spaces. The configuration of the lobby or corridor is the typical form assumed for circulation to those spaces. While the configuration of a space can vary, in the case of paths like corridors they may be open on a side (eg. Balconies), or open on either side (for columnar passages). For larger spaces, a path can be random, i.e. without any form of definition, but rather determined by the activities occurring in the space. A circulation space can be configured into any of the following forms:

- Enclosed form,
- One-sided opening
- Multiple sided opening
- Random form

(a) (b) (c)

Figure 6: Types of forms assumed by Circulation space; (a) Enclosed, (b) Open on a side, (c) Open on either side

This study aims to identify and objectify the fundamental theories of space as they relate to circulation. Spatial theories correlate the science of place cognizance and way-finding in analyzing the behaviors of humans in space. In this paper, therefore, the primary objective is to showcase the result of basic architectural theories as they apply to circulation design.

MATERIALS AND METHOD

The objective of this paper is to showcase the result of basic architectural theories as they apply to circulation design. It is noteworthy that architects and building designers are often tasked with the production of built-up spaces and the success of these tasks rests principally on design approaches adopted. This study attempts to utilize basic theories of circulation design within the context of architecture to redefine the way-finding process. It starts by examining the principles of human movement and circulation as they affect way-finding in building spaces. The identified elements and layers of circulation are eventually used in developing a design approach intended for hospital building designs. The research culminates with the justification of the way-finding factors. This is done by the application of VGA (visibility graph analysis) to review the circulation pathways adopted in the hospital design.

Study of Circulation Configuration in Hospitals

The concept of circulation in architecture has no finite description, while several studies suggest that the adoption of less complex (simpler) layouts aids in improving spatial cognitive process, others however believe that the combination of geometric configurations is necessary for navigation (Hölscher 2007). Reference to the element of good forms for circulation space design proposes the adoption of simpler geometrical forms such as squares and rectangles, cruciform, and 'L' shaped forms as essential in recognizing complexities of spatial layouts. This is owing to the significance of these shapes in the process of cognitive reaction when a person recognizes them due to their order in configuration (Passini, 1996).

For this study, this paper recognizes the most fundamental circulation geometric patterns as linear, radial, circular, and networked patterns. In the case of hospital designs, historical references are made to the primal configurations for circulation zones as presented in buildings like the Roman valetudinarian hospitals that featured a race-track-styled circulation configuration as the first double-loaded corridor system for circulation. Other configurations include that of the Monastic medical buildings from the Middle Ages that featured huge chapel-like wards that are surrounded by a group of circular supporting structures that function as the main means of circulation, shared by

people, equipment, and material supply/distributions (Thompson, 1975; Verderber, 2003; Allison, 2007). Recently owing to modernist evolutions in building designs, mega hospitals and buildings have grown exponentially in complexity and size, thus resulting in numerous spaces, with undifferentiated internal circulation zones that link scores of specialist departments in response to the new advancement in medical science. The major configurations identified by modern research for circulation in hospitals include the Linear and Radial configurations (Jiang 2016).

RESULTS AND DISCUSSION

Linear Layouts

As illustrated in Figure 7, linear configurations may be patterned as single-style corridor layout, double-styled corridor layout, 'L' shaped layout, and looped style corridor layout. These configurations are further enhanced with options like the single or double-loaded corridor system, which potentially can collect larger numbers of patient room spaces and strategically located Nursing stations and service zones.

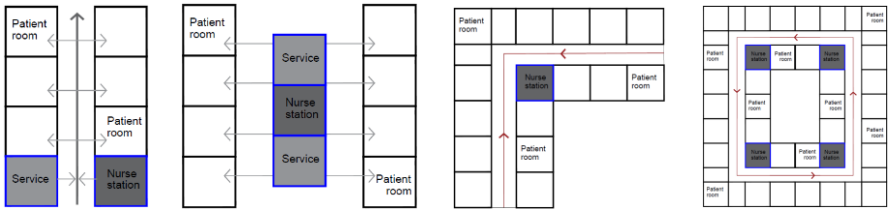


Figure 7: Types of Linear circulation configurations adopted in modern hospitals; (a) Single style corridor layout; (b) double-loaded corridor layout, (c) 'L' shaped circulation layout, (d) Lopped circulation layout

Radial Layouts

In the case of Radial layouts, the configuration is intended to bring together all the patient care areas into a central service area like a Nurse station. Such a layout option provides a direct view of all activities in all surrounding patient rooms and service zones to the Nurses in the Nurse station, while same time offering easier accessibility for the caregivers. In larger hospitals, this layout option often generates more cluster patterns, because only a few wards and patient rooms are linked to the central zones as shown in Figure 8, therefore requiring more units to accommodate the large number.

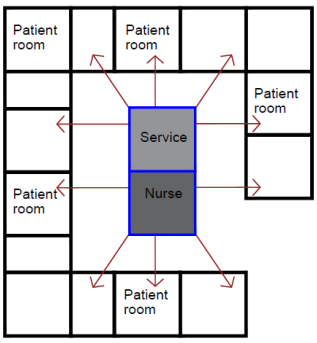


Figure 8: Radial layout configuration, showing Nursing station with a centralized service area

Proposal for a hospital circulation design using the concept of path configuration and spatial connectivity.

Spatial distribution and functional zoning in architectural design represent the preliminary stage of circulation planning and its realization is essential in defining way-finding. The configuration of the proposed design layout (as shown in Figure 9), considered the essential layers of circulation in its development to create a concept that identifies with the ease of cognizance, connectivity of paces as well as effective management of the circulation and way-finding processes. These fundamental orders of the *"Layers of Circulation"* earlier discussed in this paper are implemented in the design initialization as shown in Table 1.

Table 1: Spatial distribution and zoning concept for the proposed hospital design

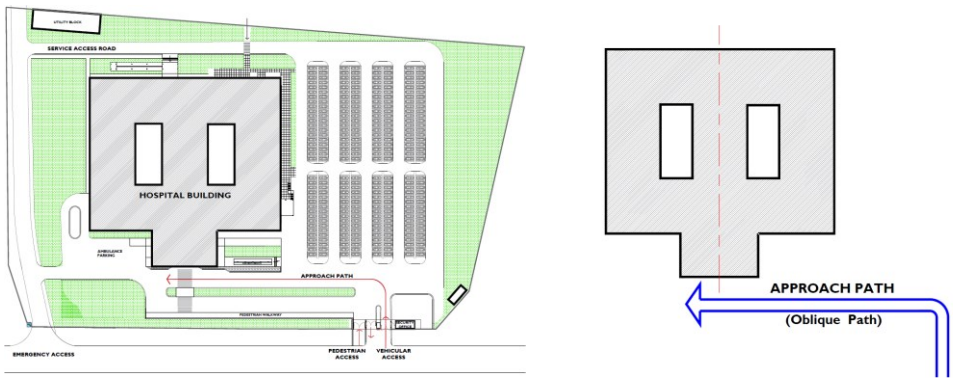
IPD (inpatient zone)	**ADMINISTRATIVE**	**OPD (outpatient zone)**	**GENERAL SERVICES**
First Level	**First Level**	**Ground Level**	**Basement Level**
- Anaesthetics - Surgery and Orthopaedics - Patient care admin. - Staff on-call lodging - Medical wards - Surgical wards - ICU wards	- Accounts - H.R. Management - Admissions - Records - Patient services - ICT services - Staff welfare	- Emergency - Surgery - Radiology and Diagnostics - Laboratories - Medicine - Treatment - Dental - Ophthalmology - Otolaryngology - Paediatrics - Obs/Gynaecology - Pharmacy	- Utility services units - CSSD - Kitchen - Laundry - Medical Gas process plant - Water treatment - Morgue services - Security/access control - Stores - CCTV/monitoring

Figure 9: Ground floor plan of the proposed hospital design

Configuration of movement paths and way-finding process in the proposed hospital design; using the "Layers of Circulation" elements

The Approach.

For the proposed design, the oblique otherwise referred to as the indirect approach was adopted. This type of approach system comes with the element of suspense, thereby permitting visitors the opportunity to view the entire building from afar.

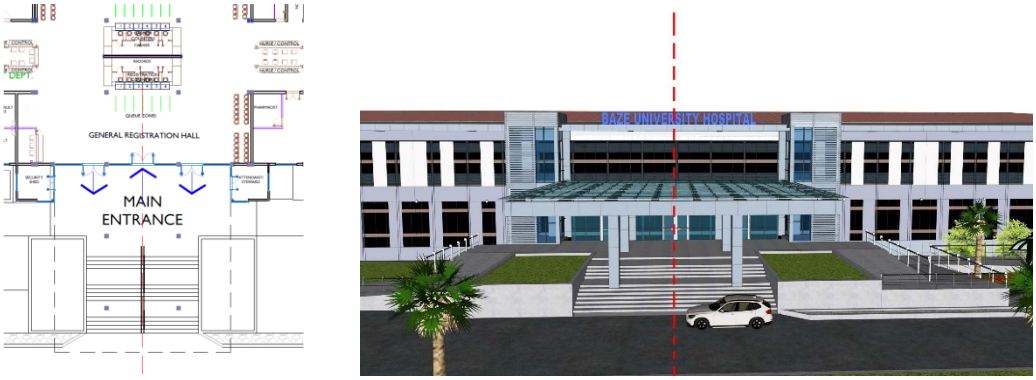


(a) (b)

Figure 10: The approach system adopted in the proposed design (a) site plan, (b) pattern of the Oblique-styled approach path

The Entrance

The entrance system adopted in the proposed design is the Projected system that is centered along the frontal plane. Internally likewise, the entrance (registration hall) is also central, thereby offering views to the leftwing, right, and central wing of the hospital for easy view and identification of destinations.

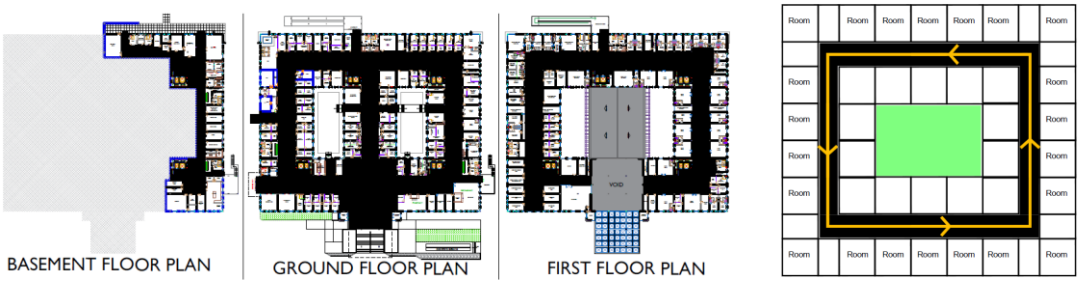


(a) (b)

Figure 11: The Centralized entrance system showing; (a) the layout of the centralized entrance hall, (b) a view of the projected entrance foyer

Path configuration.

The proposed design adopted the linear path configuration. Since the study identified that straight paths are primary configuration elements, the design adopted it as the most basic concept for ease of wayfinding and movement. To complement the way-finding process, a looped corridor system is adopted to further extend the linear path in the distribution of internal spaces and functions along the circulation path. The major impact of the loop is the possibility of returning a visitor to the starting point if lost, by the simple act of walking in a continuous line.

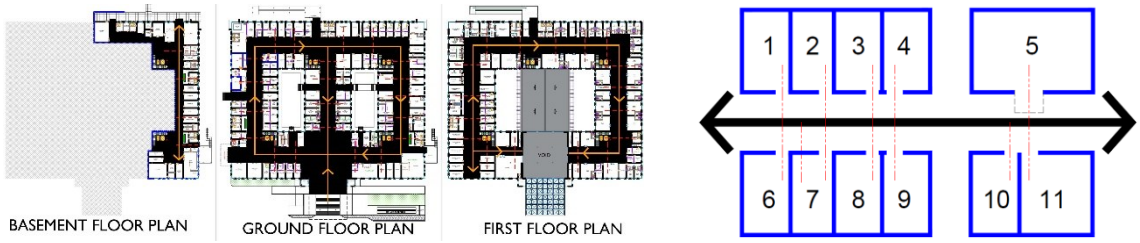


(a) (b)

Figure 12: Linear path configuration as adopted in the proposed design; (a) layouts showing the circulation path in black, (b) the Looped flow direction showing the direction of movement

Path to Space Connectivity

The proposed hospital design adopted the straight path arrangement for linking all spaces. The design provides staff, visitors, and patients with a straight connection to activity spots by the simple process of passing through corridors to identify the doorways (connectors) as shown in Figure 13.

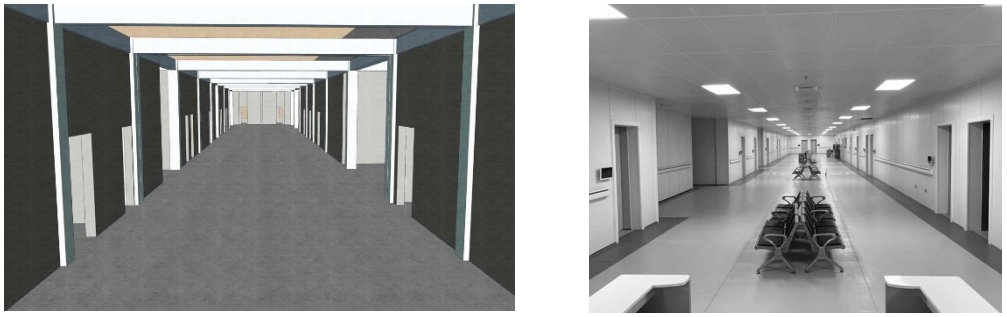


(a) (b)

Figure 13: Path to space connectivity diagram as used in the proposed design; (a) layouts showing the circulation path in black, (b) the straight path linkage system adopted for a path to space connection

Form of Circulation Space

Since the study identified that configurations, shapes, and location of a circulation space enhance the ease of identification of destinations for users, the proposed design adopted the double-loaded corridor system that is enclosed on both sides as seen in Figure 14. The final result is an 8-meter-wide corridor system which is double loaded at either side of the circulation space (corridor). The impact of this lies in the wider view angles which improve visibility and enhance way-finding during movements across the circulation spaces. It also enables the reduction of congestion and obstruction of movements often observed in conventional hospital corridors.



(a) (b)

Figure 14: The Form of the Circulation space adopted in the proposed design; (a) shows the volume of the 8m corridor way, (b) the large visibility angle which improves way-finding

VGA analysis of the proposed hospital design's circulation system

It is common knowledge that the ease of circulation and way-finding process within a building contributes greatly to its efficiency as it impacts positively the mental and psychological well-being of its users. Research identified the first stage in the process of way-finding in a space is Visibility. The process of wayfinding around large buildings can be seen as frustrating, however, this is simplified through the permission of visual access in such buildings

(Hölscher, 2007). Visibility is also seen as a component of the connectivity structure for spaces/circulation areas in buildings as they are deeply linked with choices of route and way-finding behaviours of patients and hospital visitors (Peponis et al.1990).

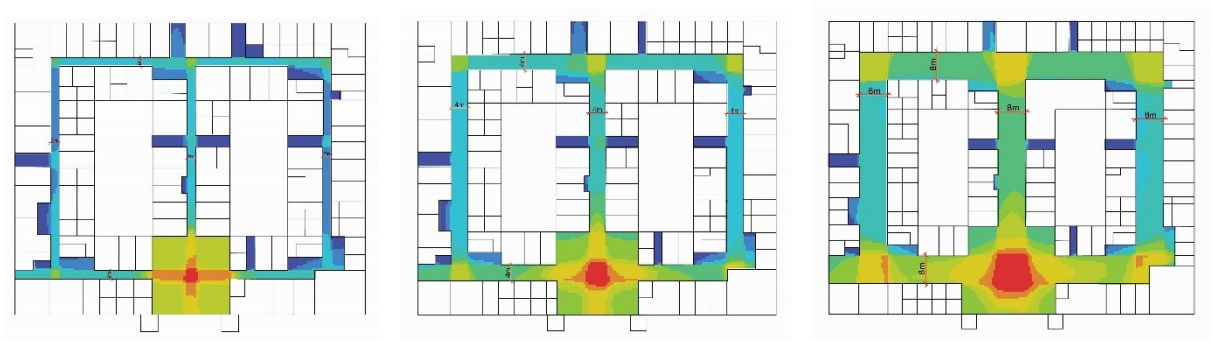
To assess the effectiveness of the hospital design with regards to its circulation system, Visibility graphs analysis is carried out to ascertain the way of finding value relative to the factor of visibility in the proposed double-loaded and looped circulation system.

Visibility graphs are representations of spaces based on isovists that are used to depict spatial configurations in circulation analysis. This is achieved by simulating visible areas in buildings with the use of simple points occurring at 360 degrees in space. This active graphical depiction provides the representation of space in real-time relative to the interior of the building and from the point of view of the building users (Pachilova 2020).

The direct observation method was adopted for this analysis. Three distinct circulation corridor sizes with a double-loaded design were observed. The significance of this is to ascertain the best configuration for effective visibility and circulation flow. The selected sizes represent the basic carriage configurations adopted in conventional hospital circulation designs. These include;

- A 2-meter wide narrow corridor,
- 4-meter wide corridor,
- 8-meter wide large corridor.

With the use of the DepthmapX 20 software for calculating visibility and isovist values, visibility graphs (VG) were generated for each of the configurations. VGA analysis was then generated from solid wall models created in AutoCAD to represent areas that are visible in the circulation space (corridor). Results of the generated visibility graph analysis are presented in Figure 15, displaying a graphical colour scheme (range of Red to Blue). The most visible parts of the circulation space are highlighted in warm colours (red, orange, yellow), while the least visible parts are represented in cool colors (green, blue).



(a) (b) (c)

Figure 15: The VGA of the 3 distinct corridor sizes considered for the proposed hospital with double-loaded and looped circulation design, (a,) the result of the VGA for a 2m corridor, (b,) the result of the VGA for a 4m corridor, (c,) result of the VGA for an 8m corridor.

VGA analysis

From the VGA analysis seen in Figure 15, the results observed conform to the conclusions that design factors are significant in determining circulation space visibility values (Turner *et al*., 2001). The graphical representations of the most visible parts of the circulation space (red, orange, and yellow) are more pronounced in the 8m wide corridors (figure 15c) than the others, while that of the 2m wide corridors (Figure 15a) displays the coolest colors (green and blue), which signifies the least visibility values. Furthermore, the visibility analysis results are expressed in Figure 16, using view sheds to signify visibility angles. In this case, the 2m wide corridor presents a lower visibility angle hence making it harder for users to view and identify their destinations from afar. However, the 4m wide corridor shows a much higher view shed indicating moderate visibility access. Finally, the 8m wide corridor presents the best visibility value as indicated by the warmer colours from the VGA analysis in Figure 15 and the wide view sheds identified in Figure 16.

(a) (b) (c)

Figure 16: Comparing the view shed and visibility angles for (a) the 8m circulation corridor, (b) the 4m circulation corridor, and (c) the 2m circulation corridor

CONCLUSION

Circulation systems and way-finding processes are essential requirements in the building design process. This study identified the major factors that affect circulation efficiency as accessibility, visibility, and connectivity. These factors identified as the fundamental Elements of Circulation are discussed in this paper and their orders are identified as the Approach layer, Entrance layer, Configuration of Path layer, Path-Space connectivity layer, and the Form of the Circulation Space layer. Also, the VGA analysis of the circulation space configuration adopted in the proposed hospital design identified the ease of wayfinding and movement as dependent on the size of circulation spaces. This is seen as significant in the patient-care service because larger view sheds in circulation spaces permit interactivity between staff that subsequently culminates in a more productive workplace environment.

Finally, having justified the significance of Visibility Graph Analysis (VGA) in way-finding studies as identified in this paper, this VGA method of analysis can be adopted by architects and designers for preliminary analysis of carriageways relative to circulation configuration during the design process of hospital buildings as to ensure improvement of circulation efficiency and way-finding.

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