TITLE

Physical Accessibility of Healthcare Facilities in Dammam, Saudi Arabia: A Space Syntax Study

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ABSTRACT

'Configurational' accessibility of healthcare buildings is an important factor for a healthy population and is an important cue to the new social awareness regarding 'right to health'.

With the increase of oil revenue and implementation of national health plans, Saudi Arabia has made large investments to health services and has commissioned many clinics and hospitals in different cities. The purpose of this research is to explore the configurational accessibility of the healthcare facilities in Dammam with special reference to three healthcare facilities that include the 350-bed King Fahad Specialist Hospital (KFSH). A detailed accessibility study of KFSH is also provided.

Configurational accessibility are the *possibilities* of access from all locations. It is a function of layout, and layout modulates where one might go, either directly from adjacent spaces, or through other intermediary spaces. This has been modelled with Space Syntax, taking axial and segmented lines, and considering topological, metric, and geometric parameters. The methodology produces different accessibility values based on connection characteristics and distance considerations. The entire city of Dammam was evaluated separately and then from the point of view of three selected healthcare facilities. In these analyses, locations of *all* the healthcare facilities in the city were mapped. The results were vetted by comparing with previous research findings and onsite observations.

This study has revealed that almost all the health facilities are located within an 800-meter or a 10-minute walking distance in all neighborhoods. This supports the expressed intention of the Saudi health policies to provide easy access to healthcare to all citizens. This is further investigated in three select medical facilities. Regarding KFSH, the campus is well related to the larger city and is accessible from many parts, making it an easy destination to get to. Inside the campus, most of the entrances of the main building have easy to accessibility, but some difficult ones were also identified. More critically, issues with entrances to other medical buildings were detected. This research is expected to be a beginning source of understanding configurational accessibility in public health studies.

KEY WORDS

Accessibility, Public Health, Space Syntax, Hospital, Saudi Arabia

INTRODUCTION

Healthcare sector is an important domain that impacts the global population and is closely linked to the development of any country. It also plays a crucial role in how a country is perceived in maintaining economic stability (Black, Ebener, Aguilar, Vidaurre, and El Morjani 2004). In this regard, access to health care by the population is an critical concern for all countries because it significantly contributes to a healthy population. Geographic accessibility, often referred to as spatial or physical accessibility, is concerned with the complex relationship between the spatial separation of the population and the locational aspects of healthcare facilities as understood by its connection network (Shengelia et al. 2003). It might be easy to understand that the level of public health of a population might be affected negatively by the distance (or access) to health care services, yet there remains limited quantitative information regarding this impact (Guagliardo 2004). Measuring physical accessibility to healthcare contributes to extensive understanding of the performance of the health system and facilitates the development of evidence-based health policies (Black et al. 2004). In this paper, 'configurational' accessibility is the focus. It is defined as a physical attribute that considers all pathways that exist between all possible origins and destinations, and is evaluated by the theories and methodologies of Space Syntax (Hillier 1984,1996).

1.0 HEALTHCARE IN SAUDI ARABIA

The inclusion of 'state-of-the-art' healthcare facilities is a significant feature of the national development of Saudi Arabia. This has been an important aspect since the first development plan in 1970 (Alkahtani 1991). The discovery of oil in Dammam substantially changed the country's economy, which affected its urban development, education, social benefits, and healthcare, among others (Mubarak 2004). Saudi Arabia is experiencing rapid urbanization and a swift increase in population. Healthcare services have been given a high priority by the government (Gallagher 2002),

and the public sector with its oil-revenue resources and central planning is the financial provider for the Saudi health system (Al-Yousuf, Akerele, and Al-Mazrou 2002).

As part of the implementation of National Development Plans, the Saudi Government allocated a large amount of money to health service provisions in line with its policy of providing health care that would be accessible to all the population free of charge. Healthcare is considered a “right”, i.e. health rights are basic human rights. The right of a person to health care is stipulated in Articles 27 and 31 of the Basic Laws of Saudi Arabia, which highlight the provision of health care in emergency, sickness, disability, and old age for all citizens. In 2006, a Saudi Patient’s Bill of Rights (PBR) was published by the Ministry of Health that affirms these health rights in its manual of policies and processes, and is further emphasized by periodic circulars (Ministry of Health, 2016; Al-Amoudi 2017).

Optimizing access to healthcare services requires fairness in the national delivery of health care facilities and equity in accessibility of citizens and health professionals, including transport to services and providers (Al-Yousuf et al. 2002). Almalki, Fitzgerald and Clark (2011) has stated that in order to improve access to services of health care in all areas of the country, a comprehensive strategy for the redistribution of health care services, involving public health care centers, general hospitals, specialist hospitals, and health professionals, should be adopted by the Minister of Health. One aspect that has not been discussed is locational characteristics. This is another way of considering access to healthcare and is understood by the relationship of the facility with all other spaces in the neighborhood or the city. This is the focus of this paper and uses Space Syntax methodology to evaluate this kind of accessibility.

2.0 SPACE SYNTAX

Space Syntax has studied the phenomenon of configurational characteristics regarding accessibility, and has proposed a robust method of measuring configurational accessibility based on identification of circulation spaces and their connection characteristics with one another (Hillier 1984, 1996). It is built on two ideas-- the objectivity of space itself, and the user's intuitive engagement with it. With its focus on space, Syntax is a theory of buildings’ and cities' layout structure. It looks at plan drawings as a set of unit spaces connected to one another -- either directly to adjacent spaces, or through a series of intermediate spaces to other spaces beyond, examines these connections, and on that basis assigns numerical measures to each space. The analysis provides quantitative measurements of individual spaces and of the whole layout (Haq 2012). In other words, Space Syntax attempts to mathematically articulate the configurational properties of space that users intuit, as expressed in the way they create specific spatial patterns in buildings and cities. Configuration in Space Syntax does not mean simply adding up the relations between pairs of spaces but trying to give an image of how a whole complex of relationships affect one other to create an accessibility structure (Hillier 2005).

Configuration may be measured for any kind of space considerations. However, Space Syntax only uses a set of predefined unit spaces in its analysis. These are convex space, axial line (Hillier and Hanson 1984), and segmented line (Turner 2001). An ‘axial map’ is set of the longest and fewest lines that can be drawn to cover all the convex spaces of a layout. It is most widely known and is the prevalent unit in literature (Hillier and Hanson 1984). Axial lines are used when studying movement (Hillier et al. 1983). In this paper these has been used to study a large hospital campus. Another form of unit space is a segmented line. Segments are formed by chopping the original axial lines at each junction into smaller individual parts (Turner 2001). This kind of analysis is employed here for city scale assessments.

Space Syntax uses various techniques to represent space as a relational spatial structure. Several measures can identify the relationships between the spatial units. By using these techniques to measure layouts, Space Syntax scholars believe they can capture the spatial and thereby the functional differences in diverse plans. Two of these measures are *Integration* and *Choice*. In simple words, integration measures how easy it is to go from one space to all other spaces of a network, indicating the potential of a space to act as destinations, or for generating to-movement. As such, one may expect to find more communal activity and many people in integrated or ‘close’ spaces. In contrast, choice measures how likely it is for a space to be chosen on shortest paths between all origins and destinations in a network, indicating its potential for through-movement (Hillier and Iida 2005). This means that more people may be expected to pass through high choice value spaces. Simply stated, in *to-movements*, people want to maximize their accessibility to all spaces, while in *through-movements*, people use a space to get to another space with the minimum effort.

2.1. Empirical findings from Space Syntax literature

Empirical studies using a Space Syntax approach to the representation and measurement of configuration have identified a general connection between configuration and various human activities, especially movement and occupancy. Studies by Peponis et al. (1989) in six Greek towns; Hillier and his colleagues (1987a) in different areas of Barnsbury in inner North London; Hillier et al. (1993) in King's Cross Area, London; Penn and Dalton (1994) in London, Rashid and Bindajam (2014) in Jeddah, Saudi Arabia and may others have examined the layout of public open space networks within cities quantified by the analysis of the axial maps, against the occupancy and movement

in those spaces. The general findings were that the integration value of streets was the most common and reliable predictor of movement density. These studies in urban areas have confirmed that the syntactic properties of spatial configuration are linked to the encounter probabilities of people and vehicles. In almost all the urban cases available, including the ones mentioned here, results indicate that there is a positive and significant correlation between space syntax derived configurational variables and both pedestrian and vehicular movement. Such findings were quite pervasive and has prompted Hillier et al., (1993) to develop their theory of 'natural movement' that essentially states that all else being equal, movement in cities can be understood by its configurational characteristics.

Regarding complex buildings, researchers such as Haq and Zimring (2003) and Haq (2003) in three large hospitals in the United States; Lu and Bozovic (2009) in three complex urban hospitals in Nanjing, China; Selota and Borgianni (2016) in three complex hospitals in Tuscany Region, Italy have published empirical studies using Space Syntax to measure the environment as a set of predictor variables for specific behavior, such as visitor movement in hospital public areas. These studies investigated the distribution of visitors and stated that the density of moving people correlated well to integration values. Also, areas with higher integration values appear to attract more visitors when in doubt about where to go. In a hospital building, the distribution pattern of visitors is similar to that of pedestrians in an urban setting, i.e., more integrated spaces have more people on average.

Hillier et al. (2007, 2010) asked if the metric analysis of cities represent real patterns. They looked closely at London and surmised at a theoretical level a strong agreement between functional differences and the patches identified. Later, Haq and Berhie (2018) commented that the relationship between them might be suggestive. In 2020 Haq investigated a few gridlike West Texas cities in the United States. He calculated the global structure using 'choice' values at radius 'n'; the local structure with metric analysis at radius '1600' meter (about one mile). They demonstrated that local patches highlight an accessible central area of every subdivision. More importantly, there is a neighborhood amenity, either an elementary school or a park located in all the central areas identified (patches). Moreover, all of these are also connected to a global core system. This indicates that the identified central patches are not only the vibrant center of neighborhoods (living centers) but are also well connected to the city structure.

3.0 METHODS

This paper is an investigation of the configurational access patterns of healthcare facilities in Dammam, Saudi Arabia. It starts by accepting the basic concepts, computerized methods and previous empirical findings of Space Syntax (Hillier and Hanson 1984). It is done on two levels – access patterns of the city, and access patterns inside the KFSH campus. On a more important note, it explores the locational characteristics of all healthcare facilities in Dammam to understand how they are connected to their neighborhoods and to the larger city.

The setting of this paper is Dammam, Saudi Arabia. This city is chosen because it is a typical Saudi city. It is also the capital of the Eastern region. It originally consisted of several hamlets that relied on fishing and pearls for their survival. It has now developed into a thriving hub of industries, commerce, and science. In this city, the roads have changed dramatically, and the city has expanded fast. The boundary of the city that is used in this study is the original boundary before the government extended it (in black, figure 1). Three healthcare facilities within the city are also selected for closer analysis. These are Bader healthcare center, King Fahad Specialist Hospital and Badee healthcare center. They are marked as A, B and C in Figure 1.

Figure1: the land use map of Dammam. Red indicates commercial areas, yellow represents residential areas, blue indicates public services such as medical facilities and universities etc., purple represents industrial and storage areas, and green indicates open spaces, green areas, and leisure. Source: (the Eastern Province Municipality website, https://webgis.eamana.gov.sa/gis/#/maps)

King Fahad Specialist Hospital (KFSH) is a large complex, and an important hospital in the Eastern region of Saudi Arabia. It was started to serve as a tertiary referral hospital providing specialized medical care to the population of the Eastern Region. Figure 2 shows the campus, including all the streets inside it and the exterior roads that are adjacent to it. The exterior roads are included because they connect to the entrances of the campus, and that some parking are located outside the boundary walls in the west. However, visitors to the main hospital can enter from many entrances. Most of the entrances are close to the main streets inside the campus, such as the main entrance of the hospital, (in axis 1 of figure 2). The outpatient department entrance, the emergency department entrance, and Cath lab entrance are in axis 2, figure 2. Also, the employees have a private entrance from the west side of the main building, which is almost invisible from the main streets (See figure 11).

Figure2: the buildings of KFSH Campus.

The network measures used in this section have already been described in the Space Syntax section. Both integration or closeness value, and choice or betweenness value are applied in this research. These are widely used to understand many urban structure-function relationships.

For axial map analysis, typically all barriers which obstruct movement are considered and the fewest and longest lines that connect all spaces to cover all the convex spaces in the layout are drawn. For this study, the axial maps of the city of Dammam and KFSH campus were based on road central lines of the street network. The axial map of the city was created by drawing lines on a separate layer above the Google map images using AutoCAD software. In total, two base maps were produced. These included an axial map of the city including KFSH campus (Figure 3), and an axial map of the KFSH campus's roads with exterior roads (Figure 4). After the basic map models were prepared, they were saved in the drawing format (DXF) and imported to Depthmap program. This is a software used to conduct a series of spatial network analysis for understanding social interactions within the spatial environment (Turner 2011). The output is a map of the area with colors from warm to cool (reds to blues) that corresponds to the range of high to low Space Syntax values. The process is shown in figure 4.

Figure3: Axial map of the city of Dammam

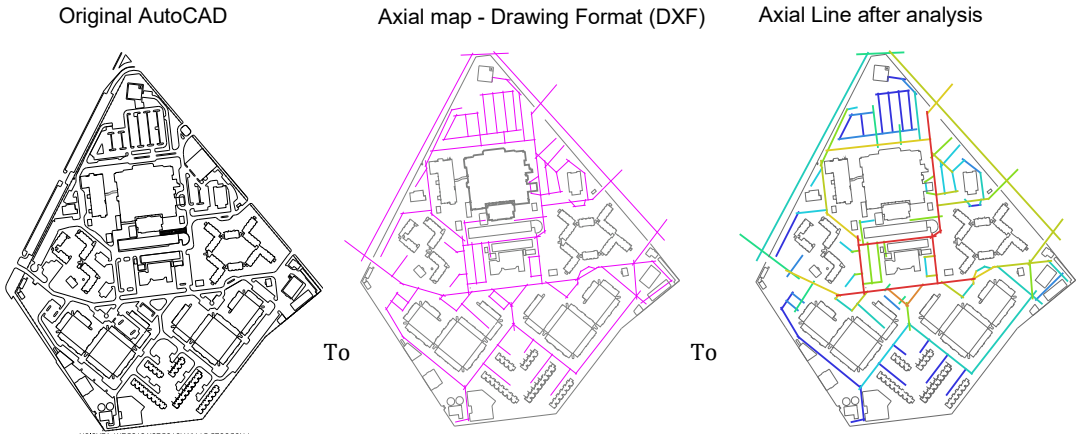

Figure 4: Process for producing data of axial map of the KFSH campus.

Space Syntax allows accessibility modelling using three measurement types: metric, topological and geometric. Metric analysis at low radii produces a diagram that shows 'patches' of neighborhood areas that are accessible at that radii. The methodology produces different accessibility values based on connection characteristics and distance considerations. Metric analysis is useful to understand areas that are more culturally biased and restrictive, and so are useful to model neighborhoods (Hillier 2010). Literature has provided ample evidence that most cities are understood globally in topo-geometric analysis, and locally in metric accessibility terms.

With Space Syntax techniques, it is possible to compute the integration values of lines at different radii. In this paper, experiments were conducted at the radii of 400m, 800m, 1600m, 2km, and infinite distance as connectivity zones to capture different urban configuration features. The integration value at radius 'n' of a line considers the total number of steps needed to cover all the lines in a given axial system.

Finally, a core map is defined as the highest ten percent of all the values of the lines in a given layout (Hillier and Hanson, 1984). This indicates the ‘spread’ of the high integration or high choice value lines over the city or campus and provides a clue of their relationship to the city functions. For example, literature informs us that integration cores indicate areas of functional centers and identify the streets that connect parts of cities to one another. Since these lines have higher concentration of commerce or are connectors between various parts of the city, a hint can be obtained regarding possible busy areas and high traffic roads.

4.0 FINDINGS

4.1 Comparison of Dammam with previous Space Syntax findings

Configurational investigation of cities done with Space Syntax methodology reveals a closeness 'structure' usually identified as an 'integration' pattern, and a 'betweenness' structure modelled as 'choice' (figure 5 and 6) Integration analysis of Dammam shows a cluster of red lines that identify a central area. Literature is very clear in demonstrating that more integrated areas are typically destination areas where one might expect functions of meeting and commerce (Hillier et al. 1993). The integrated area identified in Dammam corresponds with the city's center or downtown. This is a vibrant area that serves as a hub for various public activities such as markets, commercial activities, and government buildings. This area is mostly commercial and has the highest land values. Figure 5 also shows some integrated streets (in red) connecting the center to other parts of the city and to its edges. This makes the downtown easily accessible from all parts of the city. This center-to-outskirt connection helps sustain the downtown as a convenient location for entertainment, retail, and other public amenities that are easily accessible to citizens living in different parts of the city. Space Syntax analysis clearly brings out this function of the city.

Figure5: Integration/Closeness map of Dammam, Saudi Arabia

Figure 6 is a 'betweenness or choice' model of Dammam. This variable indicates streets that lie between origins and destinations of all possible movements within the city. These roads are therefore expected to be more crowded because of cars and pedestrians passing through (See section 2.1). The choice 'core' thus identified can be considered as the major link roads of Dammam. These link roads also serve to connect various parts of the city to one another (Hillier, Yang, and Turner 2012).

Figure6: Choice or Betweenness map of Dammam, Saudi Arabia.

In Dammam, it is additionally important to note that the radial streets identified earlier in the Integration analysis are also highlighted by the Choice analysis. Comparing figures 5 and 6, it can be said that the streets which connect the center to the edges function both as areas of commerce and as destinations, and as connection corridors for 'passing through'. A combination of integration and choice is a good representation for this phenomenon. This is shown in figure 7 that indicates clear central areas and connectors. The authors have visually verified the street functions both 'on the ground' and with land use maps obtained from municipality websites (https://webgis.eamana.gov.sa/gis/#/maps). From these, the authors can attest to the city of Dammam traffic patterns and land use distribution is as anticipated by Space Syntax literature and described in section 2.1.

Figure7: Composite values (Integration times Choice) map of Dammam, Saudi Arabia

4.2. Configurational accessibility of healthcare clinics and hospitals within the city of Dammam

Configurational pattern is also a powerful indictor of accessibility. It is so because layout has a strong influence on how people move within their environments. This is both a factor of distance and geometry. Hillier et al. 2010 had claimed that city functions are globally geometric but locally metric. In other words, he suggested that human movement at local levels (such as within their neighborhoods) are influenced more by metric distances. However, movement across large areas of the city are influenced by topology or geometric variables of the street network. This argument was, of course based on cognitive considerations. Haq (2020) had used local metric analyses to identify accessible areas within neighborhoods and has demonstrated that these areas are indeed locations of local amenities such as schools and parks. From this, he supported Hillier's assertion that spatial modelling done by space syntax with both metric and topo-geometric considerations corelate with actual use, but in two different scales.

Figure 8 shows the two kinds of Syntax analysis superimposed on a map of Dammam. The 'background' layer, shown as black 'patches', is the result of metric analysis done at a radius of 800 meters, approximately half a mile, which is considered a ten-minute walk. In other words, the background layer indicates all the neighborhood streets that are accessible by walking only for ten minutes. The foreground, colored layer is betweenness/choice values of the entire city. As explained earlier, they indicate areas of high movements. On these two layers the locations of healthcare facilities are mapped.

Figure 8 Two kinds of Space Syntax analysis superimposed on a map of Dammam showing 'background' layer of neighborhood centers and a colored 'foreground' layer that shows high choice streets that connect various parts of the city to one another. Locations of various healthcare facilities are also shown.

A careful examination of this image identifies some remarkable results. First, almost all the health facilities are located within the 'patches' of their neighborhoods. Since these patches were identified by running the metric analysis at 800 meters radius, it can be concluded that on an average, all healthcare facilities in Dammam are located within a ten-minute walk inside their neighborhoods. This is a powerful finding that indicates that the healthcare facilities are quite accessible to the citizens living nearby. Second, it is noted that a colored line either connects to, or comes very close to all the health facilities also. Since the colored lines indicate streets connected at a global level to other parts of the city, it can be further deduced that the health facilities are also accessible to the citizens of other parts of the city. From these two related observations, it can be concluded that health facilities in Dammam are easily accessible both from within the localities in which they serve, and other areas of Dammam. This was perhaps one intention of the Saudi health policy. On another note, the metric (background) analysis coupled with the geometric 'choice' analysis also indicates potential locations for future clinics and hospitals.

To further understand the configurational accessibility of these healthcare facilities, a sample of three were selected and their topological reach was calculated up to four changes in direction. (See figure 9). In other words, the question was from how far might a citizen travel to reach a health center if they could only made four turns? Since number of turns indicates cognitive complexity, a relatively lower number was chosen. The analysis in figure 9 indicates an interesting phenomenon. Because of local layout differences, each health center has a different 'reach'. Health center A has a long reach along a high choice street and goes into the downtown area (shown in blue). King Fahad Specialist Hospital (KFSH) in the middle, shown in green, reaches quite a bit of its neighboring areas, and spreads long main streets to other parts of the city. Health center C is perhaps the loneliest one reaching a few streets close by and spreading northwards. The question that crops up is this: why do the three facilities show different patterns? The answer is in the local street layout. While locating public buildings, it is worthwhile to think about its immediate neighborhood layout as well as its reach into other far away locations.

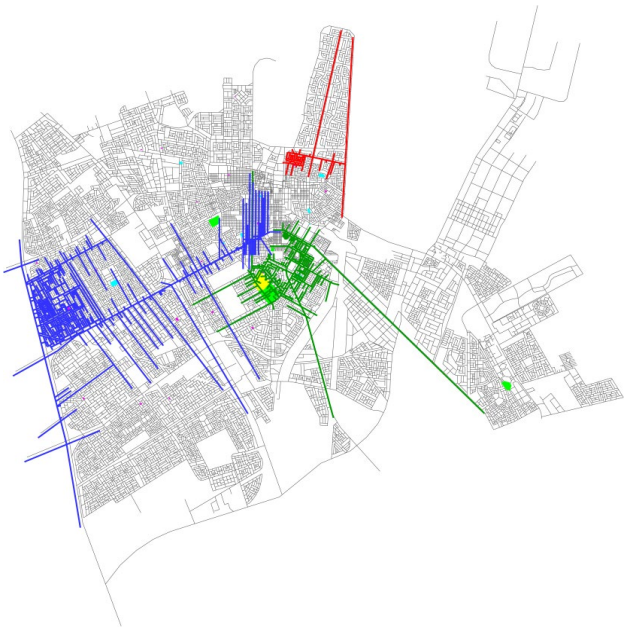

Figure 9: Reach of three healthcare facilities up to four changes of direction.

4.3. A detailed analysis of King Fahad Specialist Campus (KFSH)

At this point, this paper investigates one hospital in more detail and takes up a different system of spaces for analysis. Figure 8 shows the relationship of KFSH to the global 'choice' pattern. The hospital is adjacent to more than one road that has high choice values. As described earlier, choice/betweenness values calculated at a global (n) level indicate streets that are expected to be busy because they have higher possibilities of traffic 'passing-through'. This is the case also in Dammam. Since the high choice value of roads indicate betweenness value of roads, it can be said that the KFSH campus are accessible to most of the citizens in distant parts of the city. In comparison, the green areas in Figure 9 indicate the adjacent areas that will be considered 'close' by the citizens. For them the hospital will be accessible with only four changes in direction.

So, when citizens access KFMH, what might their accessibility experience be inside the campus? Figure 10 shows the integration or closeness analysis of the campus vehicular system. Since most of the site entrances are in the western side, and a 'crossroad' is located south of the main building, the Syntax structure tends to favor the eastern part of the main building seen by the red or orange lines. Figure 11 shows all the buildings of this campus and identifies all their entrances. Here a discrepancy is observed. While some entrances are directly off the integrated areas, there are some buildings and some entrances of the main buildings that are not. Since 'natural movement' (Hillier et. al., 1993) favors integrated areas, this discrepancy indicates a potential wayfinding issue (Haq, 2003)

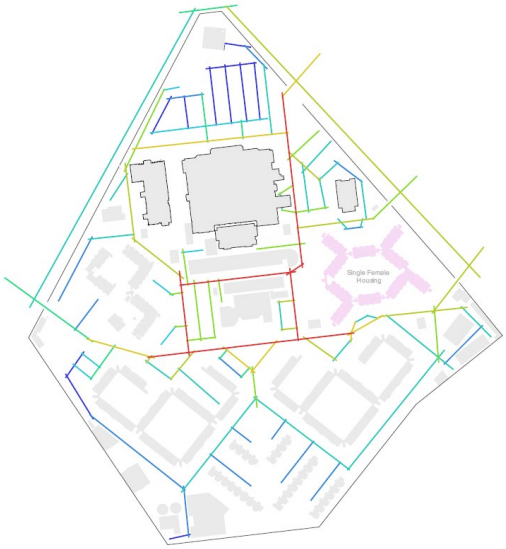

Figure 10: The axial line analysis of vehicular system of the campus; showing the integration value at radius 'n'

Figure 11: The syntactic analysis of vehicular system of the KFSH campus showing the integration core at radius 'n' (10% of all the axes)

5.0 DISCUSSION AND CONCLUSION

This paper is an exploratory study about the accessibility of health complexes within the city of Dammam. Accessibility refers to a configurational property that considers the layout of all spaces in the city, which in turn creates possibilities for movement. It includes the complex relationship between the spatial separation of the population and the locational aspects as understood by a layout's connection network. This unique condition of accessibility is modelled by using computerized techniques of Space Syntax. The theory is based on rigorous social concepts and developed over time by numerous empirical studies that have noted positive relationships between its accessibility measures and various behavioral and cognitive variables across continents.

The work described is done at three levels: the city and its relationship to the medical buildings, topological accessibility modelling of these facilities to understand the cognitive aspects, and integration/closeness study inside King Fahad Specialist Hospital. While the investigations were carried out using appropriate Space Syntax analysis, the conclusions were drawn with reference to findings that have been previously reported in the literature and visual survey of the existing conditions.

Since the Saudi Government has commissioned many clinics and hospitals in different cities to provide free health care with equal access to all citizens, this paper investigated the locational characteristics of all medical facilities in Dammam, Saudi Arabia. Most of the medical facilities are indeed connected to the neighborhoods at a ten-minute walking distance and are also part of the global system of the city, so that they connect at both local and global levels. Thus, access is easy both for the neighborhood residents and for those who wish to come from afar. In essence, this study has highlighted an often overlooked aspect of public health, which is the value of configurational accessibility with respect to the population spread. It has also demonstrated the modelling technique for investigating such configurational accessibility and decision making regarding locating healthcare facilities in large cities.

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